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DEVELOPMENT AND TESTING OF PROGRAMMING SYSTEM FOR NUMERICALLY CONTROLLED FLAME CUTTING OF SHIPS PARTS

SUMMARY REPORT

Technical Report 5.5.0
Volume 5 of Final Report
Contract NObs-4427

March 1963

TODD SHIPYARDS CORPORATION
LOS ANGELES DIVISION SAN PEDRO CALIFORNIA

FORWARD

This publication is one of six volumes of the final report on Mathematical Ship Lofting and Numerical Control of Shipyard Fabricating Equipment. The work reported on herein was performed under Bureau of Ships Contract No. NObs-4427, Code 770, during the period from April 1961 to March 1963.

The volumes of this final report have the following titles:

Vol. 1. Project Summary Report (Technical Report 9.0.0)

Vol. 2. Mathematical Ship Lofting -
Part 1. - Theory (Technical Report 1.0.0-1)
Part 2. - Operating Manual (Technical Report 1.0.0-2)

Vol. 3. Mathematical Ship Lofting - Summary Report (Technical Report 1.5.0)

Vol. 4. Programming System for Numerically Controlled Flame Cutting of Ships Parts - Operating Manual (Technical Report 5.0.0)

Vol. 5. Development and Testing of Programming System for Numerically Controlled Flame Cutting of Ships Parts - Summary Report (Technical Report 5.5.0)

Vol. 6. Numerically Controlled Shipyard Fabricating Equipment - Summary Report (Technical Report 3.0.0)

The work was accomplished by the Research and Development Group of the Los Angeles Division of Todd Shipyards Corporation, San Pedro, California. Mr. Thomas G. Smith was Project Manager for the work, and Dr. Henry A. Schade of the University of California, Berkeley, was Principal Consultant.

The Todd Staff, whose contributions and participation during the Project were responsible for its successful culmination, consisted of:

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ABSTRACT

A Parts Programming System was developed and presented to the Bureau of Ships as Technical Report 5.5.0. This report discusses that system and presents the following information:

- The background work leading to the development of the system
- Revised specifications for an automatic parts programming language for shipyard requirements
- A study and comparison of available automatic parts programming languages
- Results of production testing of the system
- A discussion of the economies of numerically controlled flame cutting
- Conclusions drawn from experience to date
- Recommendations for future action

SUMMARY

We have reviewed the background and accomplishments of the Project leading to the development of the Programming System for numerically controlled flame cutting of ships' parts, which was presented as Technical Report 5.0.0. Specifications for the parts programming language to be used with the programming system were revised during the development work and have been presented.

From a study of various available parts programming languages, the AUTOMAP II language, as written by IBM Corporation, was found to be the only language which was capable at the present time of meeting minimum requirements for a shipyard programming system.

Limited production testing of the parts programming system, employing the Air Reduction Co. "Tape-O-Graph" numerically controlled burning machine, resulted in the following determinations:

- The System is capable of accepting information from either a graphical loft or a mathematical loft. It is a more economical system when used with a mathematical loft.
- Working drawings, as presently dimensioned, are not well suited for efficient parts programming.
- Shipyard loftsmen can be trained to program for numerical control.
- The programming system as presented is workable and capable of defining the most complex parts. The most serious problem encountered was in the early failure of the tab cylinder routines of the programming language to describe curves through a series of points. Because of this problem the corrected AUTOMAP tab cylinder received only limited testing in the latter stages of the test period.
- Parts produced in the production tests were of acceptable accuracy.

Programming costs were reduced during the test period to the point where they were considered to be competitive with conventional templating costs. The potential for further reduction in programming costs is good.

It was determined that in most cases numerical control tapes can be exchanged between yards having different equipments by an additional processing run through the computer. Standardization of burning machine and director functions would permit the interchange of tapes without this additional processing operation.

The programming system as developed is ready for production use, and through such use, it can be made a more efficient system.

The type of limited testing accomplished under this Project was not adequate to determine the economies of a full production mathematical lofting/numerically controlled flame cutting process. It is recommended that economies be determined by a full production test, having no dependency on or conflicts with conventional lofting and burning procedures.

It is also recommended that programming costs be reduced by expanding the capability of the programming system and by employing design and drafting procedures which would aid in its use.

CONTENTS

ILLUSTRATIONS

TABLES

Section I

INTRODUCTION

BACKGROUND

The requirements for a "Programming System for Numerically Controlled Flame Cutting of Ships' Parts" were established and submitted to the Bureau of Ships on September 10, 1962 (Ref. 1). Fig. I-1 shows a flow diagram of the System.

In summary, it was determined that the System to be developed must:

— Be capable of accepting dimensional information from normal ship engineering/working drawings

— Be capable of accepting coordinate information from a graphical loft or coefficients of equations from the mathematical loft

— Provide capability for programming parts by tape punch typewriter or by computer

— Provide a method for checking programming accuracy

— Provide a method for nesting multiple parts on a single plate for economical cutting

— Suggest procedures for exchange of numerical control tapes between various shipyards constructing identical ships

Minimum equipment requirements of the System were also established:

— Tape punch typewriter

— Card punch

— Computer with - card input and output
- typewriter input and output
- punched tape output

— Plotter

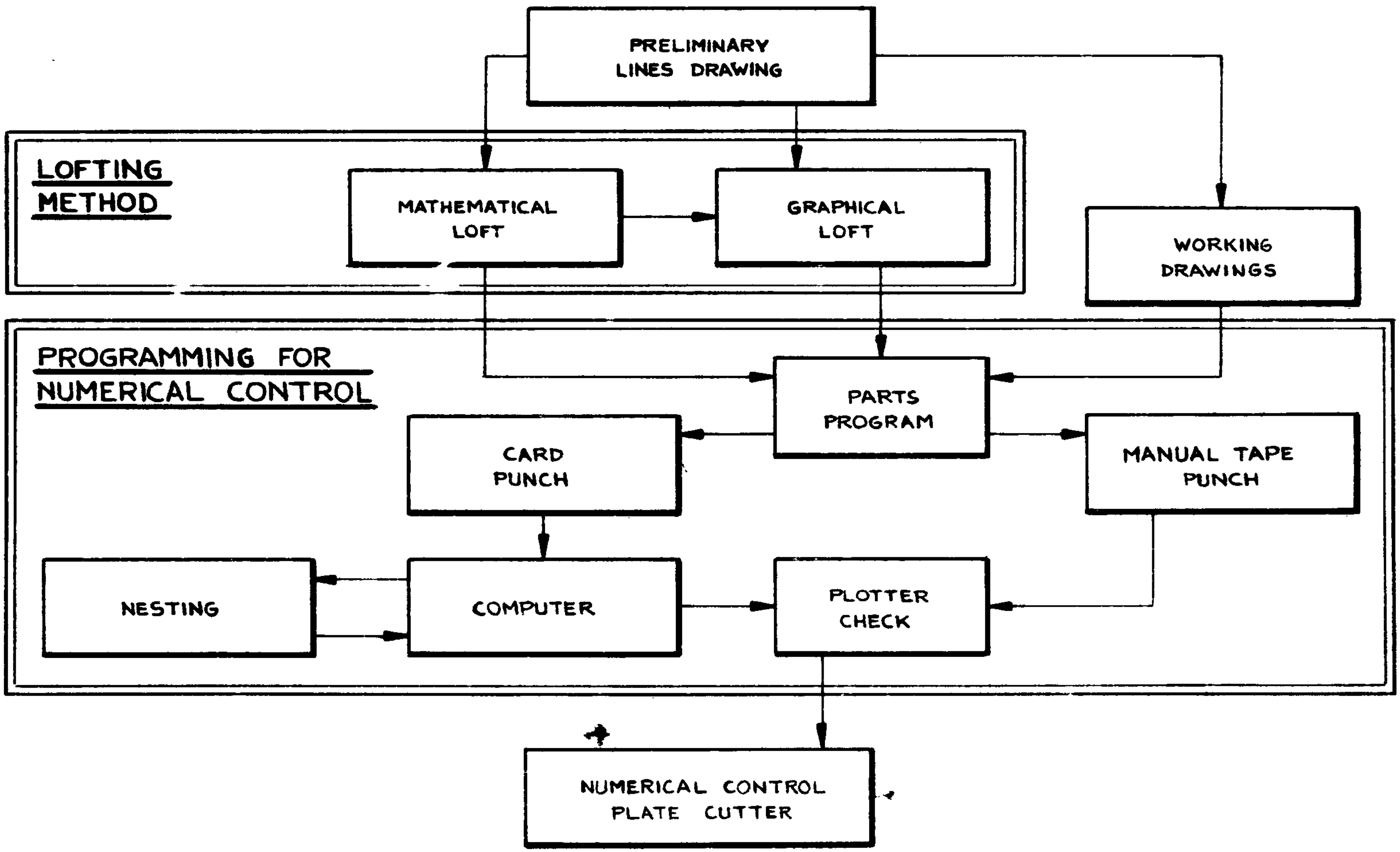

Fig. I-1 System Flow Diagram for Numerically Controlled Flame Cutting

In developing the System, efforts were aimed at producing a system which would require a minimum-cost computer configuration. The assumption was that numerical control, alone, would have to justify the acquisition , or rental costs for most shipyards.

The equipment for which the System was developed is shown in Fig. I-2 and consisted of:

— IBM-1620 computer, 60K memory, with card and tape input and output

— California Computer Products No. 560 digital plotter, connected on-line to the computer

— IBM No. 026 printing key punch

— Flexowriter No. NC-1

— Air Reduction Company, "Tape-O-Graph" flame cutting machine, with General Electric Co., Mark Century Director

An integral and important part of the proposed system is the programming language required for programming parts by computer. The specifications for the language were established and also submitted in Ref. 1.

THE PARTS PROGRAMMING SYSTEM

Having established the requirements for a proposed system, the work proceeded on the development and testing of a system to meet those requirements. Development work consisted of:

— Establishing methods and forms to be used for recording data

— Developing procedures (1) for checking accuracy of parts programs (2) for nesting multiple parts on single plates, and (3) for correcting errors in parts programs

— Writing computer sub-routines (MACROS) for repetitious operations and functions

— Testing and debugging of the System

Fig I-2 Equipment for which the System was Developed

Following the development work, the full system was designed, implemented, and production tested.*

EXPERIENCE GAINED DURING THE DEVELOPMENT WORK

During the two-year period spent in developing and testing the Programming System (and on other phases of the Contract), Project representatives visited shipyards and marine research centers throughout Europe. Research, computer, aerospace, engineering, manufacturing, and shipbuilding companies in the United States were visited and their ideas were solicited. Since the start of this Contract, efforts have been made to maintain up-to-date knowledge of industrial methods in use or in development throughout the world. As a result, much was learned about other present applications of numerical control and of the efforts to extend computer/numerical control technology into the design/engineering area.

The Bureau of Ships has been advised of some of these applications and of development work by others. Some of the conclusions and recommendations presented herein are based upon the experiences and goals of other industries with which the Project has been associated.

PURPOSE OF REPORT

The purpose of this report is to:

- Submit final parts programming language specifications, revised as a result of production testing of the System (Appendix A).
- Present a comparison of the available programming languages with the revised specifications (Appendix C).
- Present results of production tests of the System
- Draw conclusions from tests and experience gained on the Project
- Make recommendations for achieving full potential of the numerical control programming system

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*This System, complete with operating instructions, computer program listings, and flow diagrams and pertinent discussions, has been submitted to the Bureau of Ships under Contract NObs-4427 (Ref. 2)

Section II

PARTS PROGRAMMING LANGUAGES

During the early years of numerical control, users found that the problems of making control tape for parts required lengthy and time-consuming computations. The desirability of employing a computer for this purpose became apparent, and as a result, many companies wrote their own parts programming languages for use on their computers. These companies were either users or manufacturers of numerical control equipment, or were computer manufacturers. Though many languages have been written, there is a trend to standardize on just a few, depending upon the programming requirements and size of computers.

The prime example of standardization is the development of the APT (Automatic Programmed Tools) language developed by the Air Force and the Aerospace Industries. Most aerospace companies have abandoned their own language in favor of the more powerful and more universally employed APT language. The APT language was written for the large IBM-704 and 7090 computers to prepare programs for the most complex machining operations.

As numerical control was applied to new applications, generally less complex than those requiring the APT language, it became apparent that small- and medium-size computer languages were needed to make numerical control feasible for use by small manufacturing firms. As a result, such languages have been and are continuing to be written. The Air Force is now sponsoring the writing of ADAPT in an effort to develop a standard, small- to medium-size computer language.

The languages studied during this program were:

— APT (Automatic Programmed Tools) developed by the Air Force for the IBM-704 and rewritten by the Aerospace Industries Association for the IBM-7090.

- AUTOMAP (AUTOmatic Machining Program) written by the IBM Corporation for the IBM-1620 computer
- SYMPAC (Symbolic Programming for Automatic Controls) written by the Univac Division of Sperry Rand Corp., for the Univac SS-80 computer
- ADAPT (ADaption of APT) written for general use by the IBM Corporation under contract to the Air Force
- WALDO (Wichita Automatic Linear Data Output) written by the Wichita Division of Boeing Airplane Company for IBM-704 and 7090 computers
- Lockheed Numerical Control System, written by Burbank Division, Lockheed Corporation, for IBM-704 and 7090 computers
- SPLIT (Sundstrand Processing Language Internally Translated) written by the Sundstrand Corporation for IBM-1620
- COMPAC (Computer Program for Automatic Control) written by the Bendix Corporation for the Bendix G-15D computer

Each of the above languages was investigated to determine its availability for use by the shipbuilding industry and its adaptability to the shipbuilder's needs.

The results of the study, summarized in Appendix B, showed that the first four above-mentioned languages had the potential for meeting shipyard requirements, but all required some modifications or additions.

The preliminary language specifications (Ref. 1, Appendix A) were given to the sponsors of three of these four languages.* The IBM Corporation (AUTOMAP) and the Univac Division of Sperry Rand (SYMPAC) expressed an interest in expanding their languages to meet the specifications.

The Armour Research Institute, who has a contract with the Aerospace Industries Association for the maintenance of the APT program, expressed

*ADAPT, one of the four languages selected, was only in its initial stages of being written and therefore not considered for expansion.

an interest and agreed to provide the manpower, but could not fund the effort for expanding the APT language to meet the specifications.

The IBM Corporation and the Univac Division of Sperry Rand have continued to increase the capability of AUTOMAP and SYMPAC while the work of writing ADAPT has proceeded.

At this writing, none of the languages meet all of the requirements of the specifications. Though the other languages have more total capabilities, IBM's AUTOMAP II comes closest to meeting the specific requirements. A comparison of the capabilities of APT III, AUTOMAP II, SYMPAC, AND ADAPT*, with the revised shipyard specifications (Appendix A), is given in Appendix C.

The AUTOMAP (Ref. 3) and SYMPAC (Ref. 4) programs are available to IBM and Univac users, free of charge. The proprietary APT language is available only to participants in the APT program. Copies of the "Research Agreement" for full participation and "Services Agreement" for Associate Participation in the APT program are included in Appendix D.

At this writing, ADAPT has not been released for general use, and the method of distribution and maintenance of the language is unknown. It is expected that each computer manufacturer will have to implement ADAPT for his own computer after the language has been released. If this proves to be the case, it is unlikely that the language will remain "standard."

*For complete language capabilities, see the following: APT III - Ref. 9; AUTOMAP - Ref. 3; SYMPAC - Ref. 4; ADAPT - Ref. 5

Section III

TESTS

INTRODUCTION

Technical Report 5.4.0, "A Programming System for Numerically Controlled Flame Cutting of Ships' Parts," (Ref. 1) reported on the requirements established for the parts programming system and the specifications for the programming language. Since that time, the system has been developed by the Project, while IBM Corporation and Univac Division of Sperry Rand have continued to increase the capabilities of their AUTOMAP and SYMPAC languages.

Though neither language has the full capability specified, both have sufficient capability, as does the APT language, to warrant use with a full-scale production test of the system developed.

The purpose of the tests, therefore, was to establish the feasibility of flame cutting ships' parts by numerical control and to prove the ability of the System as developed to meet the requirements of ship production. Secondary to this was an attempt to learn more about the economies of programming parts for numerically controlled flame cutting.

In all instances, tests were limited by the present capabilities of the languages employed (Appendix C). No languages were sufficiently complete to permit programming, using all specified capabilities from either the graphical loft or from the mathematical loft. The tab cylinder (TABCYL)* capability was added to the AUTOMAP language during the latter stages of testing, and therefore was not tested as completely as were the other capabilities. Since the capability of that language to accept cubic

*TABCYL - a special curve fitting routine useful for converting a series of points into a continuous, smooth curve.

coefficients is part of the tab cylinder routine, this feature also received less testing than would have been desired.

SYMPAC's tab cylinder and conic coefficient capabilities were not completed in time to be tested by the Project. However, it is expected that these routines can be satisfactorily completed by the time they might be required for production use by the industry.

METHOD OF TESTING

The System was tested by programming and cutting full-scale production parts for the DLG-33, employing the Air Reduction Company's Tape-O-Graph numerically controlled flame cutting machine.

In some instances, the N/C programmers were simply assigned random parts to be nested and cut from large plates. These parts were checked by measurement.

In other instances, the programmers were assigned specific parts to be nested and cut from plates; such parts were also lofted by one-tenth scale and cut on a Schichau Monopol optically controlled flame cutting machine. In these tests, the parts for one side of the ship were cut by optical means, while the parts for the other side were cut by numerical control and then compared directly.

Tests were also made employing offsets from the graphical loft and coefficients from the mathematical loft. To perform the latter tests, it was necessary to first mathematically define a portion of the DLG-33 employing the system developed under Contract NObs-4427 (Ref.6). It should be noted, however, that the ship was partially mathematically lofted from graphically lofted offsets, only for the purposes of these tests; and it is not recommended procedure to combine the two in this manner.

Because of equipment limitations as previously indicated, the total system tested employed only the AUTOMAP language (Ref. 3). Parts programmed by the Project Programmers were programmed only in the AUTOMAP language.

To test SYMPAC (Ref. 4), dimensional data prepared by the Project was given to Univac representatives who wrote the parts programs. These programs were then run on the Univac SS-80 computer by the Rohr Aircraft Company, who in turn produced the N/C tapes.

To test APT, programs prepared by the Project were given to Northrop Corporation and North American Aviation Inc., who produced N/C tapes on their IBM-7090 computers. A General Dynamics 4020 Plotter was used to plot some parts programmed using the APT language.*

The SYMPAC and APT languages were tested only by cutting individual parts, not full plates of nested parts.

In total, over 160 test programs were written in AUTOMAP, six in SYMPAC, and three in APT. Of these programs, 144 were for DLG-33 parts which were used in the ship. Inasmuch as the basic APT and SYMPAC languages have been productively used for several years, testing of these languages was confined to only a few typical parts.

It was not our intent to cut as many production parts as possible, but rather to cut those parts which provided the best tests of the System. These parts proved to be some of the most complex parts in the ship.

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*A typical part plot is shown as Fig. II-6 of Ref. 2.

TEST RESULTS

The following test results are reported for each phase of the System, followed by general comments on accuracies.

A. Graphical Loft Information

The first tests attempted were to program and cut parts from graphical loft information. Basically, this tested the capability of fitting curves through points provided by the loft.

As previously indicated, the AUTOMAP and SYMPAC languages did not have cubic tab cylinder capability during the initial phases of the test. In order to proceed, it was necessary to write a special computer routine to fit curves and segment the curves in a series of straight lines within some allowable tolerance.

The next problem encountered resulted from inaccuracies in the offset information. These inaccuracies were wholly due to measurement errors. The problem was overcome by re-checking all offsets; but this is a time-consuming procedure, still subject to human error. Though the problem can be overcome by mathematically lofting the ship initially, if such ship is not mathematically lofted, accurate offsets can be economically determined from reduced-scale loft board through the use of a coordinatograph.

In any event, it was apparent from the tests that the offsets <u>must</u> be accurate. The programmer has no means of checking for measurement inaccuracies unless they are of sufficient magnitude to show up on a small-scale plot of the part.

The second problem encountered resulted from an insufficient number

*These early tests showed the AUTOMAP tab cylinder routine not acceptable; however, recently sample problems have been successful. In early tests the TABCYL routines failed, although the AUTOMAP version has been used successfully.

of offsets. The computer program may well run a fair curve through any given minimum number of points, but with no guarantee that the curve between those points is sufficiently close to the original graphical curve. This problem was overcome by obtaining more offsets from the loft in order to more closely approximate the original curve. Experience in selecting offsets can overcome this problem, but only at some additional cost to the overall system. Again, this is not a problem if the ship is initially lofted mathematically.

A companion problem to the insufficient offset problem encountered is that of ill-conditioned points, i.e., where the offset points are improperly spaced along the curve.

For example, points selected at basic waterline and buttock line planes may be sufficient when the curves are nearly normal to those planes; but in the bilge areas, the curve may not be adequately defined. Again, experience in properly selecting points can overcome this problem.

After having selected and rechecked an adequate number of offsets, all parts produced from graphical loft information were acceptable.

B. Mathematical Loft Information

The tests employing coefficients of equations from the mathematical loft were completely satisfactory in that there was no question of accuracy or need to fit new curves. Accuracy of the parts produced was checked to the mathematically defined hull form, rather than to the graphical hull form. All tests using mathematical loft information produced acceptable parts.

C. Combined Graphical and Mathematical Loft

These tests were the same as for Section B, above, except that they were compared against the originally lofted graphical hull form.

Though the parts produced from the mathematical loft information were sufficiently similar to the companion graphically lofted parts, this could only be ascribed to the fact that much care went into mathematically lofting a hull form which closely approximated the original graphical hull form.

It is not recommended that a ship be graphically lofted and then partially or even wholly re-lofted mathematically in order to cut some parts by numerical control. If, for example, a yard now employing an optical burning machine would like to introduce a numerically controlled burning machine into its production operation, but cannot make the complete conversion required to produce all parts by numerical control, it is not recommended that the two lofting methods be combined, as was attempted in these tests.

Under such conditions, the yard should first loft the ship mathematically, and lay down the lines thus produced to make the templates. In so laying down the lines, the loftsman must not be given the prerogative of re-fairing, but rather should be required to duplicate the mathematical hull form as closely as is practical. This procedure is common in the aircraft industry, and coordinatographs or numerically controlled drafting machines are used to plot the mathematically defined lines.

D. Engineering Information

The production tests confirmed the fact that the present method of dimensioning engineering/working drawings is undesirable for for numerical control programming. A great deal of time and labor was expended in identifying drawings by coordinate form for use by the parts programmer.

Another problem which developed was that of defining the inner edges of web frames. The working plans give very little information to define these curves, generally leaving it up to the loftsman to fit curves between two widely-spaced points.

For example, for one typical web frame, the drawing defined the inner edge of the web as a curved line to be drawn from a point 11.5 inches inboard of the molded line at the top of the part, to another point 32.6 inches in from the molded line at the bottom of the part - "the line to have a straight taper." The vertical separation between these two points was twenty feet.

A computer routine was written which would, in effect, translate, rotate, and extend the equation for the molded frame line and thereby accomplish what was believed to be the intent of the instructions on the drawing. This program now is part of the mathematical loft system. (Ref. 6.)

E. <u>Parts Programming</u>

Once having obtained the proper input data from both the design sections and the mold loft, the parts programming operation proceeded smoothly

All programming was accomplished by two ship loftsmen having no prior experience in numerical control. Though an experienced programmer was available to the Project, his function was intentionally limited to that of training the two loftsmen to program. The purpose was to learn if loftsmen could readily be trained to program, or if special skills were required.

The results here were highly satisfactory; for in less than one month, both programmers were not only skilled at programming, but were introducing time-saving shortcuts into the procedure.

The lack of a curve fitting routine (tab cylinder), during the production tests of the programming system, was a serious problem. Added time was required to obtain coordinates of intermediate points on curves close enough to approximate the hull contours.

Since the production tests, IBM has completed their AUTOMAP II tab cylinder (TABCYL) routine. Though considerable trouble was encountered in making this workable, recent tests of the routine gave satisfactory results and should be an excellent aid in reducing programming costs.

No other programming problems were encountered in the use of AUTOMAP, SYMPAC, and APT in programming ships' parts for this Project.*

F. Computer Operation

No problems were encountered in the computing phase of any of these tests.

G. Checking

During the course of the tests, several programming errors were made. In every instance, the checking routine showed up the errors so that no bad parts were produced.

H. Nesting

The nesting routine, as developed, worked very satisfactorily in every

*Parts programs employing APT, AUTOMAP, and SYMPAC languages are described in Appendix E.

test. As many as nineteen parts were nested on a single plate by this method, and there was no indication that the routine would not work satisfactorily for any reasonable number of parts.

The procedure, through repetitive use, proved to be relatively simple and efficient to use. However, the tests showed that the routine did introduce a possibility for human error. As a result, it is now recommended as part of the system that the N/C tape containing all of the parts for a single plate be plotted as a final check. The full plate plot has an additional benefit in that the marking can be indicated on it and given to the machine operator for guidance and installation of the marking. Appendix F contains a plot of a plate having an error and a plot with markings.

The Mark Century Director on the Airco Tape-O-Graph used in the tests restricts travel to a maximum of one-hundred inches for each instruction. The parts programmer must be aware of such limitations and provide the necessary additional instruction when programming a part. The nesting routine as developed does not automatically provice the necessary additional instructions when the distance to be traversed between parts is in excess of one-hundred inches; therefore it was necessary to estimate the traversing distance and add extra instructions where necessary. The nesting portion of the post processing program can be augmented with a routine which will perform this function automatically.

I. Cutting

All of the programmed functions of the machine worked satisfactorily during all tests. Fig. III-1 shows some of the parts cut during the tests. These tests, however, pointed out the programmer's need for precise information on preheat times and cutting speeds for various gasses, gas pressures, tip sizes, plate thicknesses, and materials.

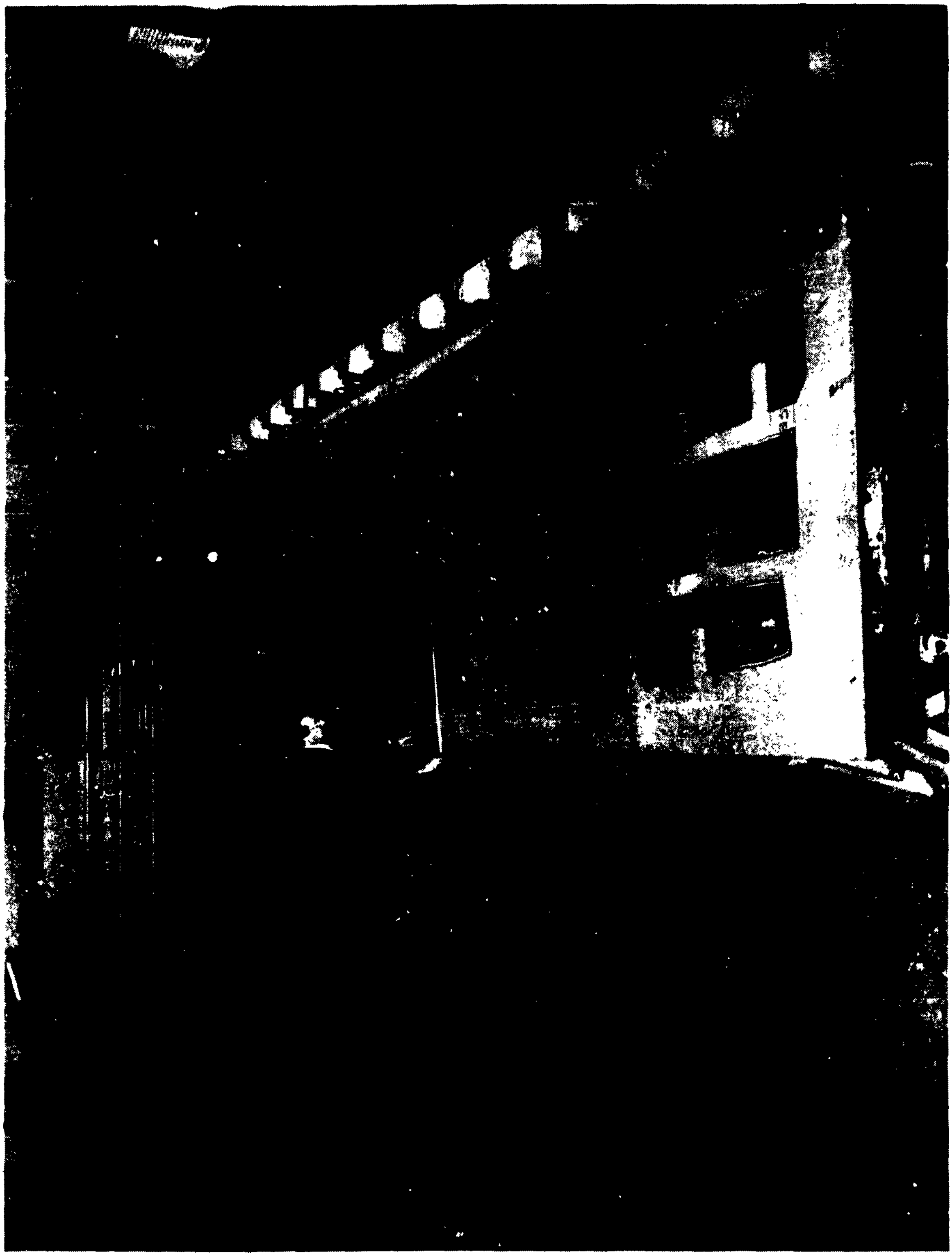

Fig. III-1 Parts Cut During the Tests

All tape controlled functions of the machine can also be accomplished by manual controls located at the operator's console. However, whenever the operator finds it necessary to "override" the feed speeds or to manually increase the dwell times, less efficient operation results. This would not occur if the programmer had the use of charts containing cutting data.

All three languages tested will automatically calculate the total cutting time required, based on length of cut and programmed speeds. This allows for improved scheduling of machine load time, as well as a management rating tool to determine shop efficiency.

In all tests, the quality of cut was good, including sharp corners. In many instances the straight line segments forming curves were quite noticeable; and to anyone familiar with the smooth curves produced by optically controlled machines, these curves looked strange. However, the cuts were within the tolerance specified.

The irregular appearance of curves can be eliminated by specifying a closer tolerance, but only at the cost of additional computer time.

J. Accuracy

The accuracy of parts produced was dependent upon four factors:

The accuracy of the input data
The tolerance specified by the programmer
The kerf width specified versus actual kerf width
The accuracy of the machine control system

The accuracy of the input data has been previously discussed, and as a result of the tests was found to be the main factor contributing to inaccuracies in parts.

In all cases, the parts were as accurate as the tolerance specified. However, through experience, a user will want to establish certain tolerance standards acceptable to production forces and the customer.

In some instances, the programmer selected the wrong kerf width, which resulted in minor inaccuracies. Here again, experience can be expected to overcome this problem.

The accuracy of the machine control system was not a subject of the tests, as there was no intention to evaluate any specific manufacturer's equipment. For those that might question the numerical control principle itself, it must be stated that, with one exception, no inaccuracies were experienced as a result of control system deficiencies.

The one exception was that, in the latter stages of testing, the machine in traversing at the highest rate of speed did not always go to the correct new starting point from the last completed part. This problem was overcome by reducing the traversing speed. Due to time limitations the manufacturer was not given adequate opportunity to correct this condition.

In summary, when the correct input data was used, all parts produced were within 1/32-inch of the specified dimensions.

Section IV

ECONOMIES OF NUMERICALLY CONTROLLED FLAME CUTTING

The total cost savings of the mathematical loft/numerical control approach over existing procedures will be determined when this new approach has been used in the construction of a full ship. Contract NObs-4427 did not require a detailed cost analysis of the System; however, time records were maintained during tests to give an indication of the costs involved in programming.

For the tests, parts programming started by employing only the basic language capability available at the time. As work progressed, MACRO instructions were written for repetitious machine functions and parts geometry (such as cutouts). In the latter stages of programming, the tabcyl and cubic coefficient capabilities of AUTOMAP were completed and incorporated into the System.

The following analysis represents the approximate average cost to prepare a tape for a ten-foot by thirty-foot plate containing five parts. These figures are representative of costs obtained during the latter stages of the testing program, using the full capabilities of the system.

Programming per part	1 hour	@	$4.00	$4.00
Key punching	1/3 hour	@	3.00	1.00
Phase I computing	10 min	@	.40*	4.00
Phase II computing	3 min	@	.40	1.20
Plotting	2 min	@	.40	.80
Nesting	1/6 hour	@	4.00	.70
Post processing (including plot)	4 min	@	.40	1.60
Total per part				$13.30
Total per plate (average 5 parts per plate)				$66.50

*Computer cost is $3,500.00 for 176 hours per month, or approximately $20.00 per hour, plus $4.00 per hour for operator.

For comparison purposes, one fairly complex part was first programmed using only the basic language, next using MACRO instructions, and finally using the tab cylinder and cub c coefficients. The resultant saving in programming time are summarized as follows:

	Written Instructions Required	Programming Preparation Time
Program using only basic language capabilities	148	2.5 hrs
Program using six of the MACRO instructions	48	.8 hrs
Program using six macros, and pre-punched coefficients and coordinates	25	.5 hrs

These figures show the substantial reduction in costs of writing parts programs achieved during the short test period, and dramatically show how costs can be reduced through experience and improvements in the System. The question that now arises is how the system can be further improved to reduce programming costs.

We have already indicated that savings will result if the necessary coordinate information is placed on the working drawings when they are made.* This does not preclude the need for the programmer to calculate coordinates, but it can be done more effic ntly at the time the drawing is made.

We can logically expect computing costs to be reduced, as they have done in the past, with each advance in the technology of constructing computers. The new IBM-1620, Model 2, which is capable of accepting this System, will reduce computing costs now by fifty percent.

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*Some dimensions would be required by production forces. This would aid not only the parts programmer, but also fabrication and erection personnel who would obtain substantial benefits from data in this form.

Further reductions in programming cost can be expected through two phases of further expansion and development of the programming system:

Phase I

Improvements can be expected rapidly through expanding the capabilities of the programming language:

Expansion of the language to meet the full shipyard specifications

Expansion of the language macro capability, particularly the ability to define large parts as macro instruction, permitting the programming of full repetitive parts with only a few statements

Phase II

Phase II improvements will not come as rapidly as those of Phase I, but they have a potential for greater cost reduction:

Design ship structure to make best use of numerical control process. Take advantage of macro capabilities in programming language. Minimize drawing of pictures and make more use of symbolic drawings and tabulated dimensions and/or coordinates.

Mathematically define more structures. Give the parts programmer equations defining the centerlines of pipes passing through a series of adjacent floors, locate lightening holes in line and give them center locations as being on a line defined by an equation, etc.

Phase I improvements can be used with the mathematically lofted hull (including mathematically defined structural intersections and sight edges) to develop a procedure in which parts programming itself can be automated.

This is not a "blue sky" concept, for it has been accomplished and is in productive use in varying degrees by other industries. For example, the Los Angeles Division of North American Aviation reports that they are preparing N/C tapes directly from design parameters using their "Autoloft" program.

Full-scale lofting and templating was in use for decades before it was improved upon by reduced-scale lofting techniques and the use of optical controls. Optical methods have been in use only a little over ten years, but already the full potential of the process has about been reached.

On the other hand, numerical control, in its infancy in shipyard application, can be economically competitive today. Already, in application by other industries, we can see the promise of cost-reducing applications yet to be developed for use by our industry. In the future, we can be sure, is a whole area of unknown and unexplored potential cost saving applications for this new tool.

Section V

COMPATIBILITY

INTRODUCTION

One of the greatest potential cost and time savings which can accrue through the use of mathematical lofting/numerically controlled flame cutting would be through the exchange of N/C tapes between yards in a multiple ship program.

Reduced scale lofting and optically controlled cutting has this same potential, and we have already seen a limited amount of exchange of information. However, this system suffers from the inaccuracies inherent in any graphical processes, as well as some variations in methods employed.*

There are many problems associated with the exchange of loft and template information, and this fact is recognized, though not discussed herein. Our concern here, is that there be some method by which control information can be exchanged between yards, regardless of the differences of equipment employed in those yards.

This section suggests a method for interchanging numerical control tapes between shipyards.

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*Differences in methods of tracing and photographing

VARIABLES

The numerical control system for flame cutting of ships' parts has at present as many, if not more, potential variables than does the optical system. These variables are:

- Type and make of computers
- Differences in parts programming language
- Type and capabilities of directors
- Type and capabilities of burning machines

Fortunately, the industry in this country has already standardized on the use of eight-channel paper tape.* There are in existence today so many makes, types, and sizes of computers, as well as many variable features between the same makes and models, that for our purposes we can assume that no standardization of computers can reasonably be expected.

The parts programming languages hold a greater potential for standardization through efforts such as the Air Force's sponsored APT and ADAPT program.

Efforts are now being made to standardize input formats for machine tool directors. Our industry should take the initiative and require standards for directors for burning machine; but today, no such standards exist, and we must be guided accordingly.

RECOMMENDED METHOD

Until such time as the language and machine director inputs are standardized, the most practical method for interchanging tapes appears to be through the post processing operation. That is, the lead yard, if provided

*At our 1st knowledge, European manufacturers had not standardized and were producing machines using both five- and eight-channel punched tape, as well as magnetic tape.

with post processing programs for the following yards' directors, can re-run their parts programs through those post processors to produce the N/C tapes for the following yards. This procedure will prove workable for most combinations of variables.

In some instances it may be necessary to write special routines into the post processing program to overcome problems of incompatibility. For example, if the lead yard's burning machine has an automatic "Light Torch" function, while the following yard's machine does not, a routine would have to be written in the following yard's post processor telling it to ignore the "light torch" function.

In summary, it now appears that, though compatibility through standardization must yet be achieved, the problems of incompatibility can generally be overcome by post processing operations.

Section VI

CONCLUSIONS AND RECOMMENDATIONS

A System has been developed and tested which will permit economical programming of numerical control in the flame cutting of ships' parts. The complete procedure has been presented, employing an available parts programming language, a computer and plotter, and a tape controlled flame cutting machine. This procedure is ready for immediate use by any shipyard.

CONCLUSIONS

The conclusions drawn from the investigation, development work, and testing accomplished in preparing this System are:

— Programming of ships' parts for numerically controlled flame cutting is economically feasible today and has a good improvement potential. However, it should not be expected to show immediate cost savings over conventional templating methods.

— The programming system will be made more efficient through productive use, as evidenced by the eighty-percent reduction in programming cost achieved during the short testing period.

— Though the System can be used employing data from a graphical loft, it is a more economical system when mathematically lofted data is used.

— The change-over to mathematical lofting and numerical control is not as straightforward as is the change from full-scale to reduced-scale lofting, for it will require changes in processes other than lofting if its full potential is to be exploited.

— A skilled loftsman can be trained to program parts for numerical control. Lofting training, the ability to read engineering drawings, and a knowledge of basic analytical geometry are prerequisites for becoming a good parts programmer. Competent persons are required to instruct in the programming and use of numerical control. Because the technology is relatively new, such instructors are not always available.

— Of the four parts programming languages available for expansion, the AUTOMAP II language written for the IBM-1620-60K computer more nearly meets shipyard requirements at the present time. It is the only language which requires no further expansion to meet minimum requirements for a competitive parts programming system employing the Mathematical Lofting System of Reference 6. However, the APT, ADAPT, and SYMPAC languages can readily be modified for use with the Mathematical Lofting System.

— Though the System provides methods for locating and correcting programming errors before parts are cut, the cost is more than for correcting errors in conventional templating systems. The process is also more susceptible to human error than are conventional systems. The economic effect of these costs have not been determined.

— Numerically controlled flame cutting can produce accurate parts in less time than can other methods. Time reductions result from the automating of (1) machine process functions, and (2) rapid traversing between parts on a plate.

RECOMMENDATIONS

Numerical control and the new techniques made possible thereby, offer the Navy and the shipbuilding industry new tools with the potential for reducing the cost of designing and constructing ships. The Programming System (Ref. 2) offers a means for taking the initial step toward exploiting the potential of these new tools.

Tests accomplished under this Project were limited to producing random complex parts to test the capabilities rather than the economies of the System. It is therefore recommended that the economies of a full mathematical lofting/numerically controlled flame cutting process be determined. This can be accomplished by a pilot installation where the lofting and programming group is given full responsibility for producing all of the parts for a large section of a ship.

Certain specific recommendations became apparent in the development stages which, if implemented, could reduce programming costs. Specifically, these recommendations are:

— Place coordinate identification on working drawings at the time they are drawn so as to minimize programming time.

— Continue to expand programming language capabilities as computer technology advances and computer costs are reduced. Investigate the use and economies of disc file and magnetic tape storage.

— With numerical control in mind, the designer can aid in reducing programming costs. For example, he can strive to design hull structural parts in such a manner that as many parts as possible can be described by standard MACRO instructions. The MACRO instructions presented in Ref. 2 represent symbolic standards for the cutouts which they define. This same type of symbolic standardization if applied to full ship parts can result in significant cost savings.

— Strive for standardization of director input data and data format.* If this were achieved, numerical control tapes could be freely exchanged between shipyards at only the cost of reproduction, regardless of the program language or computer used to prepare the tapes.

In expanding the use of computers and numerical control in flame cutting of ships parts (and in other hull fabrication applications) care must be taken to avoid developing a computer system which is too sophisticated for the needs. Cost and simplicity must be given first consideration.

Some of the above recommendations are substantiated in the reports on activities of foreign shipyards (Ref. 8) who have taken the lead in applying numerical control to ship construction and are already working on improvements such as have been recommended.

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*The "Preliminary Specifications for Numerically Controlled Flame or Plasma Arc Cutting Machines," (Appendix A. of Ref. 7), can be used as a guide in any effort to standardize burning machine functions.

Section VII

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Appendix A

SPECIFICATIONS FOR A NUMERICAL CONTROL COMPUTER LANGUAGE
(Revised January 1963)

A careful study has been made to determine the requirements for shipyard use of a numerical control parts programming language. As the primary use of this ability will be for flame cutting of flat plate, only a two-dimensional system is required.

A list of geometric definitions has been prepared using the universally known APT format. It is not a requirement, however, that the parts programming language be in this style. It is only necessary that whatever language is chosen will have the capability to define and solve these geometric descriptions.

Ships' parts can almost always be described by the use of straight lines, circles, and mathematical curves, such as cubics, conics, or curves of a higher order. In addition, many contours will be defined by the coordinates of a series of points lying in the path of the curve.

As many of these geometric situations as possible should be used, still maintaining a low-cost computer configuration. Therefore, we suggest that these routines be made modular in form and a record kept of the memory capacity required for each. A later review can then be made to determine the comparative value of cost in storage required versus expected benefits.

GEOMETRIC DESCRIPTIONS

POINTS

```
PONT02 = POINT/XCOORD,YCOORD
PONT03 = POINT/INTOF,SYMLINE1,SYMLINE2
PONT04 = POINT/**,INTOF,SYMLINE,SYMCIRCLE
         WHERE** IS XLARGE,XSMALL,YLARGE,YSMALL
PONT05 = POINT/**,INTOF,SYMCIRCLE1,SYMCIRCLE2
         WHERE** IS XLARGE,XSMALL,YLARGE,YSMALL
PONT06 = POINT/**,INTOF,SYMLINE,SYMLOFT CONIC
         WHERE** IS XLARGE,XSMALL,YLARGE,YSMALL
PONT07 = POINT/**,INTOF,SYMCIRCLE,SYMCUBIC
         WHERE** IS XLARGE,XSMALL,YLARGE,YSMALL
```

LINES

```
LINE02 = LINE/XCOORD1,YCOORD1,XCOORD2,YCOORD2
LINE03 = LINE/SYMPOINT1,SYMPOINT2
LINE04 = LINE/SYMPOINT,**,TANTO,SYMCIRCLE
         WHERE** IS RIGHT,LEFT
LINE05 = LINE/**TANTO,SYMCIRCLE1,TANTO,SYMCIRCLE2
         WHERE**IS RIGHT,LEFT
LINE06 = LINE/SYMPOINT,ATANGL,DEGREES
LINE07 = LINE/SYMPOINT,PARLEL,SYMLINE
LINE08 = LINE/SYMPOINT,PERPTO,SYMLINE
LINE09 = LINE/PARLEL,SYMLINE,**,DISTANCE
         WHERE** IS XLARGE,XSMALL,YLARGE,YSMALL
TABLIN = LINE/SYMPOINT,TANTO,SYMTABCYL
         (Note: This is different than APT II, as SYMPOINT
          must lie on TABCYL.)
CUBLIN = LINE/SYMPOINT,TANTO,SYMCUBIC
         (Note: SYMPOINT may lie on CUBIC or be so close
         that perpendicular can be drawn through point and
         cubic. At this intersection of cubic, TANLINE is
         constructed.) Example:
              CUBLIN = LINE/CUBPNT,TANTO,SYMCUBIC
TABPRP = LINE/PERPTO,TABCYL,POINT
CUBPEP = LINE/PERPTO,CUBIC,POINT
```

CIRCLES

```
CIRL02 = CIRCLE/CENTER,XCOORD,YCOORD,RADIUS
CIRL03 = CIRCLE/CENTER,SYMPOINT,RADIUS,RADIUS
CIRL04 = CIRCLE/CENTER,SYMPOINT,TANTO,SYMLINE
CIRL05 = CIRCLE/CENTER,SYMPOINT,**,TANTO,SYMCIRCLE
         WHERE** IS XLARGE,XSMALL,YLARGE,YSMALL
CIRL06 = CIRCLE/**,SYMLINE1,**,SYMLINE2,RADIUS,RADIUS
         WHERE** IS XLARGE,XSMALL,YLARGE,YSMALL
CIRL07 = CIRCLE/**,SYMLINE,**,*,SYMCIRCLE,RADIUS,RADIUS
         WHERE** IS XLARGE,XSMALL,YLARGE,YSMALL
         AND * IS IN,OUT
CIRL08 = CIRCLE/**,*,SYMCIRCLE1,**,*,SYMCIRCLE2,RADIUS,RADIUS
         WHERE** IS XLARGE,XSMALL,YLARGE,YSMALL
         AND * IS IN,OUT
```

VECTOR

```
START = INDIR,VECTOR/DELTAX,DELTAY
```

COMPOUND STATEMENTS

To simplify programming, it is convenient to be able to write compount instructions, such as an action statement combined with a line definition.

Example:

```
GOLFT,LINE/0.0,150.0,ATANGLE,0.0
          or
CIRCL1 = GOFWD,CIRCLE/CENTER,PTA,RADIUS,5.0
```

MATHEMATICALLY DEFINED CURVES

To be able to efficiently use the various types of curves encountered in the shipbuilding industry, it is desirable to have a direct entry for the equations of these curves. This requires that computer routines be prepared to handle the following:

General Cubics $AX^3 + BX^2 + CX + D$

GCUBIC/A,B,C,D

(Must have capability to accept three or more cubics to define a curve on one part)

General Conic $AX^2 + BXY + CY^2 + EY + F$

GCONIC/A,B,C,D,E,F

Tabulated Cylinder Fairing a line through N Points

TABCYL/P1,P2, ... , PN

Generally speaking, these curves are to be used in the same manner that is followed for a circle. The requirements are as follows:

AUTOMATIC SEGMENTATION

'en a special curve, cutter radius, and tolerance, the computer should calculate the path of the center line of cutter using the maximum possible chordal length for each segment, still maintaining the required accuracy.

INTERSECTIONS

Structural parts nearly always require that an intersection be generated between the lofted curve and a straight line or a circle. Therefore, computer routines should be prepared to obtain the point of intersection and/or to allow the currer path to turn from the lofted curve to this newly defined direction.

Example:

P1 = POINT/INTOF,LINE,CONIC

P2 = POINT/XSMALL,INTOF,CIRCLE,CUBIC

PERPENDICULARS

As many cutouts are located normal to the edge contour, it is essential that a line may be described as passing through a given point and perpendicular to the curved line at the point of contact.

Examples:

TABPRP = LINE/PERPTO,TABCYL,POINT

CUBPRP = LINE/PERPTO,CUBIC,POINT

ROTATION AND TRANSLATION

To nest odd-shaped parts on a metal blank, for efficient use of material and with minimum waste, it is frequently necessary to rotate and translate the coordinate axis to a more convenient position. A computer routine must be available to convert the data through a matrix, either during the Phase II operation or after the Phase II output. Many times the amount of rotation and translation desired will not be known until after the center path of cutter has been determined using the original coordinate axis. Once the size and shape of the parts have been determined in this manner, a matrix can be established.

MATRIX = XT,YT,ANGO

MACROS

To handle repetitive problems with a minimum of part programming, computer routines using MACROS as in APT III should be available. As a few of these conditions occur frequently, it is advisable to have two different types of MACROS:

<u>System Macros</u>

A special parts program consisting of tool motions to develop lightening holes, cutouts, or tapered offsets: These motions would be controlled dimensionally by variables entered into the operation at time of callout -

LTGHOL/X,Y,L,W,O

The symbolic definition, LTGHOL, would call on the system MACRO to perform all calculations necessary to define the cutter motions to create this shape.

There will be from ten to twenty of these system MACROS required to be maintained in memory or read in from card decks when called for:

1. Circle
2. Lightening hole
3. Stringer cutout, parallel sides - enter right
4. Stringer cutout, parallel sides - enter left
5. Stringer cutout, top side parallel to base line, lower side perpendicular to hull - enter right
6. Stringer cutout, top side perpendicular to hull, lower side parallel to centerline - enter right
7. Stringer cutout, top side perpendicular to hull, lower side parallel to centerline - enter right
8. Same as 7., only enter left
9. Snipe - enter left
10. Snipe - enter right

11. Stringer cutout - left side contoured for tee bar - enter right
12. Same as 11, except enter left
13. Stringer cutout - right side contoured for tee bar - enter right
14. Same as 13, except enter left

Need for additional system macro capability will be established after system is put into actual use.

Program Macros

Special repetitive operations will occur in individual parts programs in which the MACRO routine will be built up by the programmer and called for again at a later sequence. The computer provides only memory storage for these, which should seldom exceed ten motion instructions. It is anticipated that no more than three of these MACROS will ever be required in any parts program. Method of handling should be similar to that used in APT III.

The capabilities request may exceed the memory capacity of the computer. However, it is important to keep in mind that all of these modifications will never occur in any one problem. As a result of making the routines in modular form and preparing some simple manner of access, such as decks of punched cards or a magnetic tape unit, only those operations called for by the programmer need be made available and stored in memory. For example, in the case of the lofted curves, only one (either the cubic, conic, or TABCYL) will ever occur in an individual problem. There is no need, therefore, to provide storage for all three at the same time.

If the shipyards increase their interest in numerical control to the point of obtaining three-dimensional machine tools, such as milling machines, lathes, etc., they will find that the APT system is particularly beneficial when applied to the more complex machining problems.

The IBM-7090 has adequate storage capacity (on magnetic tape) to accomodate the additional capabilities specified for shipyard use. However, the work of supplementing these languages would probably have to be sponsored by the potential users.

AUTOMAP - AUTOMATIC MACHINING PROGRAM

IBM has prepared the AUTOMAP program for numerically controlled applications using the IBM-1620 - a small computer. Like APT, the programming language used standard, English-like expressions which greatly simplify the work of the parts programmer.

The AUTOMAP program is available in two basic packages:

AUTOMAP I - written for the 1620 computer with only 20K storage. Within this capacity, the language lacked many features necessary for shipyard use.

AUTOMAP II - written for the 1620 computer with 60K storage. The language contains the tab cylinder, general cubic, and macro capabilities so essential to programming ships' parts.

If the language were to be enlarged to meet all shipyard requirements, more core storage would be needed. The added cost of this core could offset the advantages gained through having the enlarged language capability. An alternative to this would be to re-program AUTOMAP for an IBM-1620 - 20K, with the new 1311 disc pack. The rental cost here would be less than for a 60K unit, and the capacity would be increased.

The AUTOMAP program will be available, free of charge, either from the IBM Corporation or from the 1620 Users Group.

Appendix B

COMMENTS ON NUMERICAL CONTROL LANGUAGES INVESTIGATED

APT III - AUTOMATICALLY PROGRAMMED TOOLS

This Automatic Programming System for control of machine tools was developed as a joint effort of the Air Force (Air Materiel Command) and the AIA (Aerospace Industries Association).

It is a very versatile system, but so large and complex it may only be used on the largest computers available, such as the IBM-7090. (This has been the only computer used for the APT III program to date, though the Univac Division of Sperry Rand Corporation is modifying the program to fit its 1107 model and expects to have it available by mid-year.)

This program uses simple English-like expressions to describe both the geometry of the part and the tool motion instructions. In addition, it automatically handles most of the necessary calculations required to establish the complex intersections which determine the path of cutter.

The AIA has contracted with the Armour Research Institute to manage, maintain, and improve APT III. Through financial support from member firms, work is continuing on the development of this system. Non-members wishing to use APT may participate by joining the "APT Long Range Program," either as full or associate members. This would allow them to obtain all the computer data required, as well as the various instruction manuals. (See contract information on APT in Appendix D.)

Though APT requires a computer too costly for most shipyards, it is possible that inexpensive control tapes can be made on computers at nearby service bureaus having such facilities.

If the shipyards increase their interest in numerical control to the point of obtaining three-dimensional machine tools, such as milling machines, lathes, etc., they will find that the APT system is particularly beneficial when applied to the more complex machining problems.

The IBM-7090 has adequate storage capacity (on magnetic tape) to accomodate the additional capabilities specified for shipyard use. However, the work of supplementing these languages would probably have to be sponsored by the potential users.

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If the language were to be enlarged to meet all shipyard requirements, more core storage would be needed. The added cost of this core could offset the advantages gained through having the enlarged language capability. An alternative to this would be to re-program AUTOMAP for an IBM-1620 - 20K, with the new 1311 disc pack. The rental cost here would be less than for a 60K unit, and the capacity would be increased.

The AUTOMAP program will be available, free of charge, either from the IBM Corporation or from the 1620 Users Group.

SYMPAC - SYMBOLIC PROGRAMMING FOR AUTOMATIC CONTROLS

The Univac Division of Sperry Rand Corporation has prepared, with the aid of personnel from Rohr Aircraft, their own automatic part programming system, called SYMPAC.

This is used on the Univac, medium-size, general-purpose computers - the SS-80 or SS-90. The program uses a combination of English and coded numerical expressions to describe the geometry of the part to be cut. Though this is not quite as simple a language as is used in the APT-type computer program, it can be readily learned and used by shipyard personnel.

The program is available from Univac free of charge to Univac SS-80 or SS-90 users. The Univac SS-80/90 have adequate storage capacity to accomodate the additional capabilities specified for shipyard use.

ADAPT - ADAPTION OF APT

To obtain a computer system similar to APT, but useable on smaller, less costly electronic computers, the Air Force Materiel Command has given a development contract to the IBM Corporation for preparation of this system.

The specifications call for ADAPT to be compatible with APT as much as possible. The same English expressions are to be used to describe geometry and motion. Because of the limited capacity of the many computers considered for its use, many APT features will be omitted.

ADAPT, written in Fortran, is nearly complete and ready for release to computer manufacturers. Although some computer manufacturers may make the system available to customers by July 1963, much testing and debugging can be expected before ADAPT can be used in production.

A comparison of the benefits of this sytem with other available languages should be made when ADAPT is completed.

WALDO - WICHITA AUTOMATIC LINEAR DATA OUTPUT

The WALDO system is a special parts programming language prepared for use in the IBM-704 and 7090 series computers. It was prepared by Boeing's Applied Computing Services Center, Boeing Airplane Company, Wichita, Kansas, for use solely by the various Boeing Divisions.

Because of the proprietary nature of the system, very little is known about its capabilities. The Boeing Airplane Company has advised the Project that it is discontinuing its use of WALDO in favor of the APT method.

This language was considered not available for shipyard use.

LOCKHEED NUMERICAL CONTROL LANGUAGE

Engineers of the Burbank Division, Lockheed Corporation, worked several years developing a computer system to simplify the work of numerically controlled tape preparation. This language was prepared for use in the IBM-704 and was subsequently modified for use in the larger IBM-7090.

When requested to furnish information regarding the system, Lockheed representatives stated that it was never put into a package suitable for use by outside interests, and they do not intend to offer it for this purpose as the cost would be excessive. They further stated that Lockheed is converting all divisions to the use of APT and will gradually abandon the use of their own system.

The language was considered not available for shipyard use.

SPLIT - SUNDSTRAND PROCESSING LANGUAGE INTERNALLY TRANSLATED

The SPLIT system is a computer program prepared by Sundstrand Corporation, Rockford, Illinois, for use in an IBM-1620 computer. In this program, minor calculations are performed automatically within the computer, generating in one pass the offset data necessary for machine tool control.

This sytem is capable of handling only straight lines and circles, plus the auxiliary functions required by certain machine tools. More complex shapes, such as the mathematical curves required by the shipyard industry, cannot be processed.

Because of the small capability of the SPLIT system, and because it is proprietary, the language was considered not available for shipyard use.

COMPAC - COMPUTER PROGRAM FOR AUTOMATIC CONTROL

The Bendix Industrial Controls Division of the Bendix Corporation was one of the early leaders when, in 1957, they released the COMPAC numerical control programming system.

This system was prepared especially for an all-Bendix operation, consisting of a Bendix G-15D computer and the Bendix tape-controlled director of machine tools. The tape used for input data to the director, is a seven-channel, straight binary format. Although COMPAC requires no separate post-processor, only the older model Bendix directors can accept tape with this format. All new directors require the eight-channel tape with binary-coded decimal, in accordance with AIA standards. Though post processor systems can be developed for these new directors, there seems to be no activity in this regard.

At the present time, less than half-a-dozen firms throughout the United

States are known to be using the G-15D for numerical control computing, and some of these firms are converting to the more general use of the IBM-7090 and the APT system.

The Bendix Computer Division has discontinued the manufacture of the G-15D and have concentrated on their larger G-20 model computer.

Though no numerical control routines are available at this time for the G-20 computer, the ADAPT system as being prepared by the Air Force probably could be easily converted for its use.

The COMPAC language was considered not available for shipyard use.

Appendix C

COMPARISON OF APT, AUTOMAP, SYMPAC, AND ADAPT WITH SHIPYARD SPECIFICATIONS

The attached Tables 1 to 4 show a comparison of the capabilities of the four languages with the revised shipyard specifications (Appendix A).

The information on APT capabilities is based upon APT III as released in December 1961. We were advised by the Armour Research Foundation on July 11, 1962, that "APT III can meet all specifications (though not necessarily using the specified format in all cases) except those involving cubics".

The information on AUTOMAP and SYMPAC is current, since the IBM Corporation and Univac Division of the Sperry Rand Corporation have worked closely with the Project.

The information on ADAPT capability was taken from IBM Corporation's report on the writing of the language (Ref. 5). At this writing, the language is understood to be completed, but has not been released for use.

Since none of the four languages meet all of the specifications, and since the individual capabilities vary in importance, a discussion of the information contained in the Tables follows.

POINTS (Table 1)

Of the eight methods specified for defining points, the five most important methods to the shipyards are:* 02, 03, 04, TABPNT, AND CUBPNT. Method 06, employing conics, may be used if the hull is defined by conic equations.

All four languages have sufficient capability for describing points to

*Assuming the mathematical lofting system as developed under NObs-4427 is used (Ref. 6).

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program ships' parts. By adding other method specified but not available (particularly TABPNT and CUBPNT), programming labor cost would be reduced, but may require more memory for some computers, thus increasing computer costs.

For example, AUTOMAP II (shipyard) requires all of the core storage of an IBM-1620-60K computer. To increase the language to include all of the specified definitions not now in AUTOMAP II would require an additional storage capacity. The savings in programming time might be offset by additional computer cost, or the additional storage could be justified for other reasons, such as the capability to use very large Macros for describing a complete part.

LINES (Table 2)

All four languages have adequate capability to define lines, except for the TABLIN, CUBLIN, TABPRP, and CUBPRP definitions - all of which are considered important to an efficient operation.

CIRCLES (Table 3)

Only the ADAPT language is lacking a circle definition considered essential to ship parts programming. It lacks definition 06, a circle tangent to two lines, which is frequently needed to define ships' parts.

As a result of the producting tests, Definitions 07 and 08 for circles were added to the specifications. Though not required to program ships' parts, these definition capabilities could be expected to reduce programming costs if they were available.

MISCELLANEOUS (Table 4)

Vectors

Only SYMPAC language has no vector capability, but it does have a substitute capability which is adequate for the purpose.

General Cubic

Only AUTOMAP has the capability to accept general cubics; this is of primary importance when the hull is mathematically defined by cubics. In this respect, only AUTOMAP has been specifically expanded to be compatible with the mathematical lofting developed under Contract NObs-4427 (Ref. 6).

TabCyl

Though all languages are listed as having tabcyl capability, the ADAPT tabcyl has not been tested by the Project, and to date, only the AUTOMAP tabcyl routine has produced satisfactory curves for ships' parts.

This capability is considered important to the shipbuilding industry and is really the only tool for programming hull form or inner bottom contours if the ship has not been mathematically lofted. Since it is doubtful that a ship will ever be one-hundred percent lofted (an assumption based on Aerospace and our own experience), the availability of good tabcyl routine should be a big factor in the selection of a parts programming language.

Rotation Matrix

All languages except AUTOMAP have a rotation matrix capability within the language itself, though AUTOMAP's macro capability can be used in a similar but limited manner. However, the rotation and translation capability required for nesting multiple parts on a plate is best as a function of the post processor. Only the AUTOMAP post processor for the GE Mark Century now has this capability, but it would probably not be a difficult function to add to other post processors.

Macro Capability

The SYMPAC language is the only one of the four languages lacking macro capability, and it is understood that the capability cannot be added to the language in its present form. This is considered to be a strong factor against the selection of SYMPAC for programming ships' parts because the capability substantially reduces programming costs.

Scale Factor

Scale Factor was not included in the original specifications but has been shown in making the comparison because of the convenience in having this capability.

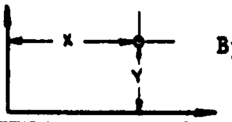
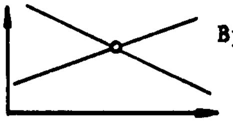
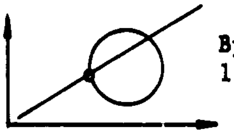
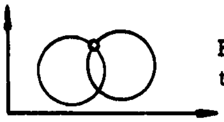
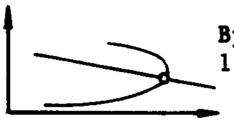
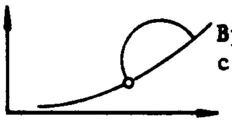
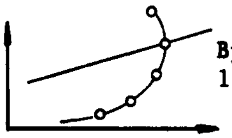
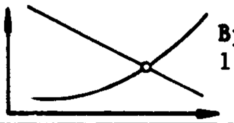
Of the four languages, only AUTOMAP does not have this capability. It has, however, been written into the AUTOMAP GE Mark Century post processor, which accomplishes the purposes when that post processor is used.

Compound Statements

All four languages have capability to accept compound statements, and since this capability has been found to reduce programming costs, it has been added to the specifications.

TABLE 1

COMPARISON OF LANGUAGES WITH REVISED SHIPYARD SPECIFICATIONS

POINTS		Item of Specs.	APT	AUTOMAP	SYMPAC	ADAPT
	By X and Y coordinates	02	YES	YES	YES	YES
	By intersection of 2 lines	03	YES	YES	YES	YES
	By intersection of line and circle	04	YES	YES	YES	YES
	By Intersection of two circles	05	YES	YES*	YES	YES
	By intersection of line and conic	06	YES	NO	NO	NO
	By intersection of circle and cubic	07	NO	NO	NO	NO
	By intersection of line and tabcyl	TABPNT	YES	NO	NO	NO
	By intersection of line and cubic	CUBPNT	NO	NO	NO	NO

*Not given in Programmers' Manual, but language has capability

TABLE 2

COMPARISON OF LANGUAGES WITH REVISED SHIPYARD SPECIFICATIONS

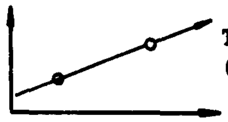
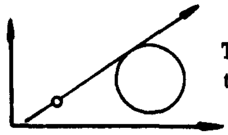
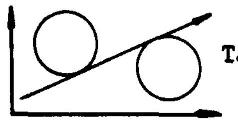
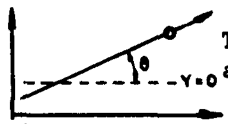
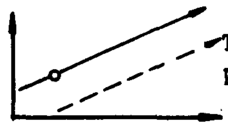
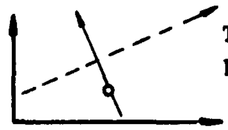
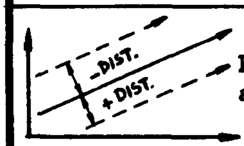
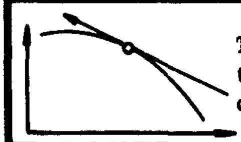
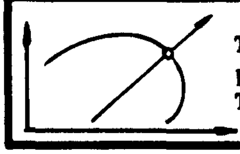
LINES		Item of Specs.	APT	AUTOMAP	SYMPAC	ADAPT
	Through two points (coordinates or symbolic)	02	YES	YES	YES	YES
		03	YES	YES	YES	YES
	Through a point tangent to a circle	04	YES	YES	YES	YES
	Tangent to two circles	05	YES	YES	YES	YES
	Through a point at an angle	06	YES	YES	YES	YES
	Through a point and parallel to a line	07	YES	YES	YES	NO
	Through a point and perpendicular to a line	08	YES	YES	YES	YES
	Parallel to a line and a given distance away	09	YES	YES	YES	YES
	Through a point and tangent to a TabCyl or curve	TABLIN	YES	NO	NO	NO
		CUBLIN	NO	NO	NO	NO
	Through a point and perpendicular to a TabCyl or curve	TABPRP	NO	NO	NO	NO
		CUBPRP	NO	NO	NO	NO

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TABLE 3

COMPARISON OF LANGUAGES WITH REVISED SHIPYARD SPECIFICATIONS

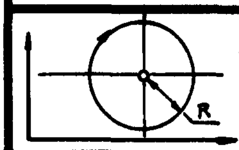
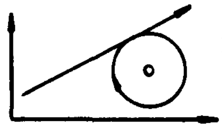
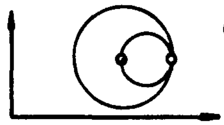
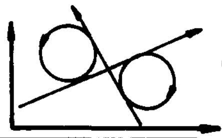
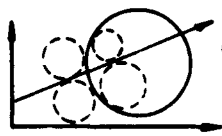
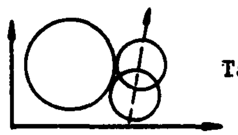
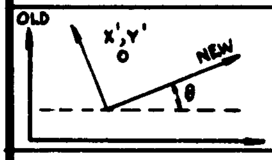
CIRCLES		Item of Specs.	APT	AUTOMAP	SYMPAC	ADAPT
	By a point and radius (coordinate or symbolic point)	02	YES	YES	YES	YES
		03	YES	YES	YES	YES
	By a point and tangent to a line	04	YES	YES	NO	NO
	Centered at a point and tangent to another circle	05	YES	NO	YES	YES
	Tangent to two lines	06	YES	YES	YES	NO
	Tangent to a circle and a line	07	YES	NO	YES	NO
	Tangent to two circles	08	NO	NO	YES	NO

TABLE 4

COMPARISON OF LANGUAGES WITH REVISED SHIPYARD SPECIFICATIONS

MISCELLANEOUS	Item of Specs.	APT	AUTOMAP	SYMPAC	ADAPT
<u>VECTOR</u> Given by AX , AY , AZ	YES	YES	YES	NO*	YES
<u>GENERAL CUBIC</u> $X = AY^3 + BY^2 + CY + D$	YES	NO	YES	NO	NO
<u>GENERAL CONIC</u> $AX^2 + BXY + CY^2 + DX + EY + F = 0$	YES	YES	NO	YES	YES
<u>TABCYL</u> Faired curve through known points	YES	YES	YES	YES	YES
 Rotation Matrix	YES	YES	NO**	YES	YES
<u>PROGRAM MACRO CAPABILITY</u> For repetitive action statements	YES	YES	YES	NO	YES
<u>SCALE FACTOR</u> For reduced or enlarged scale	NO	YES	NO**	YES	YES
<u>GO DELTA</u> To move cutter a given distance	NO	YES	YES	NO	YES
<u>COMPOUND STATEMENTS</u> A combined action statement and definition	YES	YES	YES	YES	YES

*Not necessary in SYMPAC system

**Not in language but is in post processor

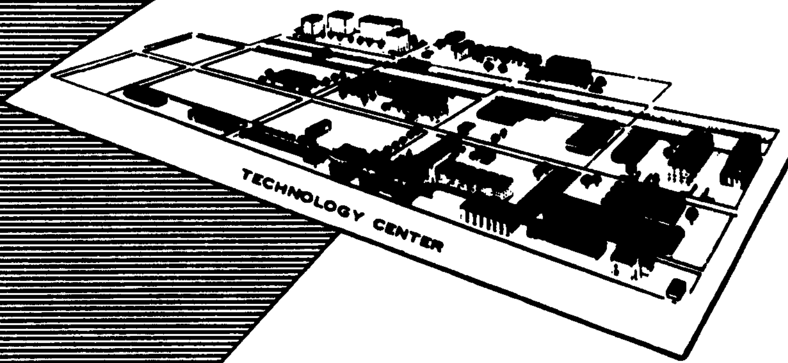
Appendix D

CONTRACT INFORMATION ON APT

This Appendix contains a copy of the Armour Research Foundation "Research Agreement" which provides for full membership in the "APT Long Range Program. Also included is a copy of their "Services Agreement" for associate participation in the APT Long Range Program.

ARF

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY



RESEARCH AGREEMENT

APT LONG RANGE PROGRAM

RESEARCH AGREEMENT

AGREEMENT dated as of the 1st day of September, 1961, between ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY, a not-for-profit Illinois corporation (hereinafter called the "Foundation"), as party of the first part, and various organizations executing this or counterparts of this Agreement (hereinafter sometimes called the "Participating Organization"), when referred to collectively, and sometimes called the "Participating Organization" when referred to severally) as parties of the second part.

WITNESSETH:

In furtherance of the development of the Automatically Programmed Tools (APT) Project and to continue the work of the most recent effort carried on by certain member companies under the sponsorship of the Aerospace Industries Association (AIA), known as the APT III Short Range Program, to accelerate the long range development of the APT Project, to provide the benefits of such research to American industry generally, to develop manufacturing methods which can assist mobilization of industry for the defense of the United States, and to provide adequate facilities for investigating, analyzing, and exploiting new technological discoveries in computer applications, the AIA has recommended to its interested membership that a single APT contractor be selected for such purposes.

The Foundation has been selected by the Manufacturing Committee of the AIA to solicit participation in the long range development of APT from the membership of the AIA as well as other organizations interested in the APT Project, and therefore proposes to conduct and in good faith successfully complete the long range APT development program under terms and conditions hereinafter set forth.

IT IS THEREFORE AGREED between the parties hereto as follows:

Section 1 - Certain Agreements by Foundation

(a) As its principal obligations under this Agreement the Foundation proposes to the Participating Organizations that the Foundation conduct, manage and maintain a research and development program directed toward the continued development and application of the APT system (hereinafter referred to as the "Project"). Foundation agrees to assign the necessary technical and supporting personnel, and provide such equipment and facilities and other services as may be required to meet the Project objectives which are more specifically set forth in Exhibit A attached herto and made a part hereof.

(b) The initial term of this Agreement is estimated as a period of sixteen months from September 1, 1961, and the payments stipulated in Section 3 hereof are calculated on this estimated period of performance subject to the limitations of Section 3 hereof.

(c) It is recognized by the parties hereto that all the tasks and objectives set forth in Exhibit A may not be accomplished within the period of this initial Agreement and, therefore, effort on the Project will be directed in accordance with priorities and schedules established by the APT Management Council referred to in Section 2 hereof.

Section 2 - APT Management Council

An APT Management Council is established to provide in addition to other responsibilities and authorities which may be assigned to it a medium through which the parties may cooperate in effecting a reasonable and expeditious transition of the APT III Short Range Program heretofore conducted under the sponsorship of the AIA. The Management Council shall be composed of the following members:

Vice Chairman, AIA Manufacturing Committee
Vice Chairman, AIA Aerospace Manufacturing Engineering Committee
Vice Chairman, AIA Numerical Panel
AIA Numerical Panel/APT Project Chairman
AIA APT Project Assistant -- Part Programming
AIA Project Assistant -- Computer Programming

Section 3 - Project Fund

It is estimated that minimal Project objectives can be accomplished over the sixteen month period for a cost of two hundred and twenty-five thousand dollars ($225,000). In the event a minimum of fifteen Participating Organizations have not executed this Agreement on or before December 31, 1961, or the number of participants although less than fifteen which have executed the Agreement on or before December 31, 1961, shall not have agreed to contribute proportionately the minimum amount of money required, the Foundation shall have the option to terminate the Project and pro-rate actual costs incurred as set forth in Section 7 hereof.

Section 4 - Payment by Participating Organizations

The Participating Organization, in consideration of obtaining all rights hereunder for not more than one of its operating divisions, agrees to pay to the Foundation the sum of fifteen thousand dollars ($15,000) upon delivery of the executed Agreement to the Foundation. The Participating Organization set forth on the signature page hereto, at any time during the term of this Agreement or any extension hereof, shall be entitled to have any of its divisions or subsidiaries in consideration of the payment of five thousand dollars ($5,000) for each of such divisions or subsidiaries acquire all rights hereunder, except those pertaining to Rebates and Credits in Section 5 hereof.

In consideration of the contributions made by the United States Government to prior APT research programs, Government installations shall have the right to become a participating organization and entitled to full rights hereunder for the payment of five thousand dollars ($5,000) each and shall be entitled to all rights hereunder, except those pertaining to Rebates and Credits in Section 5 hereof.

Section 5 - Rebates and Credits

Foundation agrees that any funds received by it from Participating Organizations will be used for the objectives and purposes of this Project, and that if the number of Participating Organizations is such that a total research fund in excess of five hundred thousand dollars ($500,000) is established for the term of this Agreement, any sum in excess of five hundred thousand dollars ($500,000) will be divided equally by the number of Participating Organizations (excluding any Division or subsidiary of a Participating Organization of a Government installation) and established as a credit to be refunded to each Participating Organization or to be applied to any sum which may become due and payable by virtue of any extension to this Agreement as provided for in Section 12 hereof.

Further, if the Agreement is not extended as provided for in Section 12, unexpended funds will be equally divided by the number of Participating Organizations and a rebate made in equal amounts to each Participating Organization.

Section 6 - Additional Rights of Participating Organization

In addition to the rights specified elsewhere in this Agreement, each Participating Organization shall receive:

(a) An introductory indoctrination course to qualified personnel of the Participating Organization.

(b) Monthly progress reports in such form and detail as is established by the APT Management Council.

(c) Summary technical reports to be issued as the results of the Project dictate.

(d) Such training manuals and training aids as are developed during the course of the Project.

(e) Participation in a minimum of two technical meetings to be conducted by the Foundation for the purpose of disseminating information on the progress of the Project.

(f) A basic amount of decks and documents developed on the project.

(g) The right to reproduce any of the documentation and data outlined above, a through f, for its use and for the purpose of training its personnel located in any of its other divisions or subsidiary.

Section 7 - Charges and Audits

For the Foundation's services hereunder charges will be accumulated on the following basis:

The actual cost of compensation paid by the Foundation to its technical staff assigned to the Project for work on the Project (part-time services being pro-rated), plus an overhead charge to cover the cost of Foundation's general facilities, equipment and administrative expenses, and plus also the cost, at established rates, of work performed in Foundation's service shops especially for the Project, as well as the cost of special supplies and equipment required for the Project and traveling and other miscellaneous expenses pertaining thereto, subject however to the approval of the APT Management Council of any items of capital equipment. Semi-annual operating financial statements of the Project will be furnished to the APT Management Council by the Foundation.

In the event this Agreement is terminated in accordance with the provisions of Section 3 hereof actual costs as determined by the above method of application shall be equally pro-rated to the Participating Organizations during the term of the Agreement.

The APT Management Council shall have the right to request a financial audit of the records of the Project. Such audit, if requested, shall be conducted by an independent firm of Certified Public Accountants, and the cost thereof paid for by the Participating Organizations independent of the sums provided for in Section 3 and 4 hereof.

Section 8 - Patents and Copyrights

(a) Patents. The Foundation shall be the sole owner of any and all patentable inventions relating to the subject matter of the Project which hereinafter may be made by staff members of the Foundation assigned by Foundation to the Project, during the time they are performing work on the Project and as a result thereof, as well as any and all patent applications and patents disclosing said inventions. Foundation agrees to grant to Participating Organizations, severally and not jointly, a personal non-exclusive, royalty-free license under any and all inventions accruing to Foundation hereunder. Further, Foundation shall promptly disclose to the APT Management Council any patentable idea which is conceived on the Project and will recommend a course of action on the disposition of such idea. In the event that the said Management Council does not approve the prosecution of a patent, the Foundation shall, nevertheless, have the right to apply for the same. Any net income derived by the Foundation from patents which are acquired as a result of this Project and were prosecuted with Project funds shall be first devoted to research and development in the area of numerical control.

(b) Copyrights. The Foundation shall be the sole owner of any and all copyrights stemming from this Project. Foundation agrees to grant to Participating Organizations severally and not jointly, a personal non-exclusive, royalty-free license under any and all copyrights accruing to the Foundation hereunder.

Any cost and expenses for the prosecution of patent applications approved by APT Management Council incurred by Foundation pursuant to (a) above shall be paid for by the Foundation from the fund provided in Section 3 hereof.

Costs and expenses incurred by Foundation pursuant to (b) above shall be paid for by the Foundation from the fund provided for in Section 3 hereof.

The Foundation, to the extent possible and practicable, will obtain copyright protection on material produced under this Agreement.

Section 9 - Proprietary Rights

Neither the Foundation nor any Participating Organization shall have the exclusive or proprietary right to any information or results of the Project. The Foundation and the Participating Organiations shall nevertheless have an equal but not exclusive right to use the information and results furnished under the Project. Further, neither the Foundation nor any Participating Organization shall have any right to sell or market or otherwise receive compensation for the exchange of documentation, duplication or any of the basic data obtained from this Project except as herein provided in Section 8.

Section 10 - Conflicting Projects

The Foundation agrees that it will not during the term of this Agreement knowingly undertake any other investigation which in its opinion conflicts with the Project, and it is further agreed that the Foundation will not be required to undertake any work under this Project which conflicts with any other program at the Foundation.

Section 11 - Special Requirements of Participating Organizations

Participating Organizations desiring services beyond the scope of the Project, but relating to APT, shall have the right to request assistance from the Foundation. Foundation agrees to perform services for Participating Organizations at its established industrial rates under the following conditions:

(a) Rendering of the requested individual services will not jeopardize the overall APT Project, and

(b) A mutually satisfactory agreement covering the work is entered into between the Participating Organization and the Foundation.

Section 12 - Term of Agreement

As provided in Section 1(b) the initial term of this Agreement is sixteen months from September 1, 1961. Foundation grants to Participating Organizations the option to continue the program for an additional period of twelve months beyond the term of the instant Agreement provided that, in the opinion of the APT Management Council, a sufficient number of Participating Organizations execute and deliver to the Foundation a mutually acceptable extension agreement on or before October 15, 1962. Foundation agrees to present to Participating Organizations the proposed extension agreement on or before September 1, 1962. It is understood that the Foundation will continuously solicit active participation from all United States firms, institutions and agencies and installations of the United States Government.

Section 13 - Publication by Participating Organizations

Participating Organizations agree to submit to Foundation all advertising, sales promotion, and other publicity matter relating to the Project wherein the name of the Foundation is mentioned or language is used from which the connection of the Foundation therewith may, in the judgment of the Foundation, reasonably be inferred or implied; and the Participating Organizations shall not, without the prior written approval of the Director of the Foundation, publish or use such advertising, sales promotion, or publicity matter. Participating Organizations further agree that they will not voluntarily use any information obtained from the Project as evidence in any law suit or administrative proceeding without the prior written approval of the Director of the Foundation, which approval shall not be unreasonably withheld; provided, however, that nothing herein shall be deemed to restrict the use of such inform .ion in connection with the obtaining or enforcement of Participating Organizations' patent rights. It is understood that Participating Organizations and Foundation will endeavor in good faith to keep confidential, through the application of reasonably prudent security standards, and disclose to no one without the consent of the APT Management Council, any new process, device, machine, or composition of matt relating to the Project - provided, however, that nothing shall be deemed secret or confidential which is described in any prior printed publication or patent, or is publicly known in the industry. Likewise, the Foundation shall not use the name of any Participating Organization without its approval.

Section 14 - Counterparts

This Agreement may be signed in a number of counterparts, each of which shall be signed by the Foundation and by a Participating Organization, and all of which collectively shall be deemed to be one and the same instrument. Participation in this Agreement by any one organization shall be in consideration of the participation of each of the other Participating Organizations as well as in consideration of the obligations to be undertaken by the Foundation.

Section 15 - Assignment Prohibited

No Participating Organization shall have the right to sell or otherwise dispose of all or any part of its rights under this Agreement without the prior written consent of the Foundation, and the Foundation is prohibited from assigning or transferring this Agreement or the performance thereof without prior approval by the Participating Organizations and the APT Management Council.

Section 16 - Termination

Unless this Agreement is extended as provided in Section 12, this Agreement shall terminate December 31, 1962. It is further agreed that individual Participating Organizations may terminate their participation at any time during the term of this Agreement. In the event such termination is elected by a Participating Organization it shall not be entitled to any refund of any payments made hereunder, but it shall retain only those rights which have accrued to it as of the date of such termination, including all license and use rights under Section 8 hereof.

Section 17 - Nonliability in Certain Events

Neither party shall be liable in any way for failure to observe or perform any provision of this Agreement if such failure shall be caused by any law, rule or regulation of any constituted public authority or shall be due to any cause beyond the control of the party in default.

Section 18 - Notice

All notices required or permitted hereunder shall be in writing and be deemed given sufficiently if sent by ordinary or registered mail, postage prepaid, addressed to the Armour Research Foundation, or to a Participating Organization, as the case may be, at its address last furnished in writing to the party giving such notice for the purpose of receiving notices, or if no such address shall have been so given, then at its address indicated below, and such notice shall be deemed given and received when it is deposited in the United States Mail.

ARMOUR RESEARCH FOUNDATION
OF ILLINOIS INSTITUTE OF TECHNOLOGY
10 West 35th Street
Chicago 16, Illinois

By ______________________________
Its

ACCEPTED:

By ______________________________
Its

EXHIBIT A
SCOPE OF PROJECT ACTIVITIES

INITIAL PERIOD (September through December, 1961)

During the initial four months, Armour Research Foundation personnel will work closely with members of the present APT III staff at San Diego and effect a smooth transition of responsibility for the APT system. Monthly progress reports will be issued to participators summarizing transition progress.

REGULAR PERIOD (January through December, 1962)

The Foundation will perform the following tasks as modified from time to time by the APT Management Council, placing emphasis in accordance with the priority indicated by the ordering. As tasks, or portions of tasks, are completed, full information on the work accomplished will be released forthwith to the Participating Organizations.

I. CARRY-OVER TASKS

Several tasks are to be considered carry-overs from the 1961 APT Project and are of prime importance in expanding APT capability. These are:

A. Multi-Axis Simultaneous Control

Since a considerable number of machines having four and five axes will soon be installed, a very important early task will be to extend the present APT system capability beyond the simultaneous path and position control for machines having up to three axes. Post processor development for these new multi-axis machines must also be carried out.

B. Post Processor Standardized Skeleton and Dispatcher

If a post processor is separated into a machine geometry module and a control system module, and these modules are developed independently for future post processors, a much more efficient and flexible method of developing post processors is attained. This allows for any machine geometry module to be combined with any control system module through use of a dispatcher program. Investigation and implementation of these techniques will be of major importance in the APT Project.

C. Polyconic and Ruled Surfaces

These geometry types, frequently called large surface definitions, are important in producing fuselages, wings, pods, or other large portions of a vehicle. Much effort has been expended on this task in the past year to include such surface definition in the APT system and it is important that this work be completed in 1962.

D. Additional Tasks

In addition to the high priority carry-over tasks mentioned, several other areas of work can be undertaken depending on the constraints of time and cost in 1962. These lesser priority tasks would be selections from the following:

1. Limit surfaces
2. Integration of AUTOPROMT
3. Mesh of points surface
4. Conic sectionalized surface
5. Diagnostic program extension
6. Decision surfaces
7. Z surface extension
8. Output verification
9. Cutter geometry extension

II. SYSTEM MAINTENANCE AND COORDINATION OF FIELD APPLICATIONS

To assure satisfactory APT system performance, reliability, and standardization for all participators, each of the following areas of effort must have high priority and be fully and properly documented:

1. Standardized correction of quick-fixes
2. Standardized revisions of system faults
3. Answers to participators' questions
4. Maintenance of selected post processors developed prior to December 31, 1961

III. DOCUMENTATION AND TRAINING

Considerable effort will be devoted to documentation and training in accordance with the requirement set forth in the body of this agreement. The following items are of major importance:

1. Issuance of monthly progress reports to participators
2. To arrange and conduct participators' meetings and introductory indoctrination sessions
3. Maintenance and distribution of basic documents
    a. General training manual
    b. Part-programmer's manual and dictionary
    c. Computer programming manual
    d. Operations and systems manual
    e. APT theories and techniques
    f. Basic program decks

IV. DIRECTED APPLIED SYSTEM DEVELOPMENT

As new APT system concepts are devised and shown to be feasible, a schedule for their implementation will be established by the Foundation. The following areas of development are a minimum set for consideration in 1962:

1. Lofting and drafting
2. Inspection
3. Standard airfoil surfaces (overlaps with ruled surface development mentioned under I)

V. NEW COMPUTING EQUIPMENT AND PROGRAMMING TECHNIQUES

As computers other than the IBM 709 or 7090 are utilized by APT participators, consideration will be given reprogramming and other related tasks which will best serve participators' needs. The effect of new languages, such as ALGOL, and new computing equipment will be considered.

VI. NEW NUMERICAL CONTROL HARDWARE DEVELOPMENT

As new equipment and controls are announced and installed, Foundation personnel will keep close track of such developments and of their effect on the APT system. The needs of the participators will be served by full examination of such new developments and consideration of APT extensions to utilize the full capability of these machines and equipment. Some of the principal facets to be explored for such new developments are:

1. Call, special function, and parameter words for part programming
2. Computer program capability for translation, compiling, and data calculation.
3. Post processor additions to provide proper output of machine control instructions.

VII. RESEARCH AND ADVANCED DEVELOPMENT

Continued evolution and expansion of APT system capability requires that the Foundation must develop and prosecute a considerable amount of research relating to numerical control. The Foundation fully intends to conduct research and advanced development in this and related projects and to serve as a center for information in numerical control. A few of the areas of applied research which will be investigated are:

1. Mathematical dimensioning
2. Automatic feed rate and/or spindle speed computation
3. Cutter wear compensation computation
4. Output of manufacturing control data such as for scheduling, loading, and cost control
5. Use of computers for design with integration into the APT system.

SERVICES AGREEMENT

Agreement effective as of the 1st day of January 1962 between ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY, a not-for-profit Illinois corporation (hereinafter called the "Foundation"), as a party of the first part, and various organizations executing this or counterparts of this Agreement (hereinafter sometimes called the "Associate Participants", when referred to collectively, and sometimes called the "Associate Participant", when referred to severally) as parties of the second part.

WITNESSETH:

The Foundation, pursuant to agreements entered into September 1, 1961, with certain member companies of the Aerospace Industries Association (AIA) and other interested industrial companies and government installations, undertook to conduct, and is presently conducting, an accelerated, long range developmental research project on Automatically Programmed Tools (APT) in furtherance of the recent APT III Short Range Program carried on by members of AIA. The APT Project is directed at developing manufacturing methods which can assist mobilization of industry for the defense of the United States, and establishing adequate facilities for investigating, analyzing, and exploiting new technological discoveries in computer applications.

In order to offer the benefits of the APT Project to a larger segment of American industry and encourage its interest therein, the APT Management Council has requested the Foundation to establish an Associate Participation membership category which, for a limited cost, will entitle an Associate Participant to a portion of the materials and services furnished by the Foundation under he APT Long Range Program, in accordance with the terms and conditions hereinafter set forth.

IT IS THEREFORE AGREED between the parties hereto as follows:

Section 1 - Certain Agreement by Foundation

(a) As its principal obligations under this Agreement the Foundation proposes to furnish one copy of the following materials and the services listed below to Associate Participants:

1. APT Dictionary
2. Part Programming Manual
3. Part Programming Maintenance Service
4. Part Programming Maintenance Releases
5. Introductory Course on Part Programming
6. Technical Reports relating to Part Programming
7. Part Programmers Technical Meetings
8. APT Progress Reports

Foundation will schedule an Introductory course in Part Programming and two Part Programmers Technical Meetings during the term of this Agreement.

(b) The initial term of this Agreement is a period of twelve months from

1 January 1962, and the payment stipulated in Section 3 hereof is based on this period of performance. Foundation grants to Associate Participants the option to extend their rights hereunder for an additional period of 12 months beyond the term of the instant agreement, provided such Associate Participants execute and deliver to the Foundation a mutually acceptable extension agreement on or before November 15, 1962. Foundation agrees to present the aforesaid extension agreement to Associate Participants on or before October 1, 1962.

Section 2 - Option to Participate in APT Long Range Program

An Associate Participant shall have the further right, during the term of the agreement, to become a Participating Organization in the APT Long Range Program upon execution and delivery to Armour a copy of the Agreement covering participation in the APT Long Range Program. In the event an Associate Participant exercises this right the sum specified in Section 3 hereof shall be applied as a credit to the sum due for participation in the APT Long Range Program.

Section 3 - Payment by Associate Participants

The Associate Participant, in consideration of obtaining all rights hereunder, agrees to pay the Foundation the sum of Five Thousand Dollars ($5,000.00) upon delivery of an executed Agreement to the Foundation. The Foundation agrees that this sum will be used exclusively for the objects and purposes of the APT Project.

Section 4 - Proprietary Rights

No Associate Participant shall have any right to sell or market or otherwise receive compensation for the exchange of documentation, duplication or any of the data obtained under this Agreement. The Foundation shall be the sole owner of any and all patentable inventions relating to the subject matter of the Project which hereinafter may be made by staff members of the Foundation assigned by Foundation to the Project, during the time they are performing work on the Project and as a result thereof, as well as any and all patent applications and patents disclosing said inventions. Any net income derived by the Foundation from patents which are acquired as a result of this Project and were prosecuted with Project funds shall be first devoted to research and development in the area of numerical control. The Foundation shall be the sole owner of any and all copyrights stemming from this Project.

Section 5 - Special Requirements of Associate Participants

Associate Participants desiring services beyond the scope of this Agreement but relating to the Agreement, shall have the right to request assistance from the Foundation. Foundation agrees to perform service for Associate Participants at its established industrial rates under the following conditions:

(a) Rendering of the requested individual services will not jeopardize the overall APT Project, and

(b) A mutually satisfactory agreement covering the work is entered into between the Associate Participant and the Foundation.

Section 6 - Publication by Associate Participants

Associate Participants agree to submit to Foundation all advertising, sales promotion, and other publicity matter relating to this Agreement wherein the name of the Foundation is mentioned or language is used from which the connection of the Foundation therewith may, in the judgment of the Foundation, reasonably be inferred or implied; and the Associate Participants shall not, without the prior written approval of the Director of the Foundation, publish or use such advertising, sales promotion, or publicity matter. Associate Participants further agree that they will not voluntarily use any information obtained from this Agreement as evidence in any law suit or administrative proceedings without the prior written approval of the Director of the Foundation, which approval shall not be unreasonably withheld.

Section 7 - Counterparts

This Agreement may be signed in a number of counterparts, each of which shall be signed by the Foundation and by an Associate Participant, and all of which collectively shall be deemed to be one and the same instrument. Participation in this Agreement by any one organization shall be in consideration of the participation of each of the other Associate Participants as well as in consideration of the obligations to be undertaken by the Foundation.

Section 8 - Assignment Prohibited

No Associate Participant shall have the right to sell or otherwise dispose of all or any part of its rights under this Agreement without the prior written consent of the Foundation, and the Foundation is prohibited from assigning or transferring this Agreement or the performance thereof without prior approval by the Associate Participants and the APT Management Council of the APT Long Range Program.

Section 9 - Termination

Unless this Agreement is extended, as provided in Section 1(b) hereof, it shall terminate December 31, 1962. It is further agreed that individual Associate Participants may terminate their participation at any time during the term of this Agreement. In the event such termination is elected by an Associate Participant it shall not be entitled to any refund of any payments made hereunder, but it shall retain only those rights which have accrued to it as of the date of such termination.

Section 10 - Nonliability in Certain Events

Neither party shall be liable in any way for failure to observe or perform any provision of this Agreement if such failure shall be caused by any law, rule or regulation of any constituted public authority or shall be due to any cause beyond the control of the party in default.

Section 11 - Notice

All notices required or permitted hereunder shall be in writing and be deemed given sufficiently if sent by ordinary or registered mail, postage prepaid, addressed to the Armour Research Foundation or to an Associate Participant, as the case may be, at its address last furnished in writing to the party giving such notice for the purpose of receiving notices, or if no such address shall have been so given, then at its address indicated below, and such notice shall be deemed given and received when it is deposited in the United States Mail.

ARMOUR RESEARCH FOUNDATION OF
ILLINOIS INSTITUTE OF TECHNOLOGY
10 West 35th Street
Chicago 16, Illinois

By____________________________
Its

ACCEPTED:

By____________________________
Its

Address:

Appendix E

TEST PROGRAMS USING APT, AUTOMAP, AND SYMPAC

This Appendix shows a sketch of a sample part (Fig. E-1) which has been programmed using APT (Fig. E-2), AUTOMAP (Fig. E-3), and SYMPAC (Fig. E-4).

The AUTOMAP and APT methods use nearly identical English-like expressions, while the SYMPAC version uses a numerical code with some alphabetical terms.

Both APT and AUTOMAP allow the use of time-saving MACROS, but for comparison, these are shown only in the AUTOMAP version.

In the APT parts program, we have used the capability of APT to accept several geometric descriptions as a single compound statement. This reduces the number of lines of programming required but does not materially save time.

The reader can easily follow the method used in each of the programs by referring to the part sketch.

POINT	X	Y
A	10	0
B	15	15
C	7	12
D	1	12
E	2	
F	−3	−3

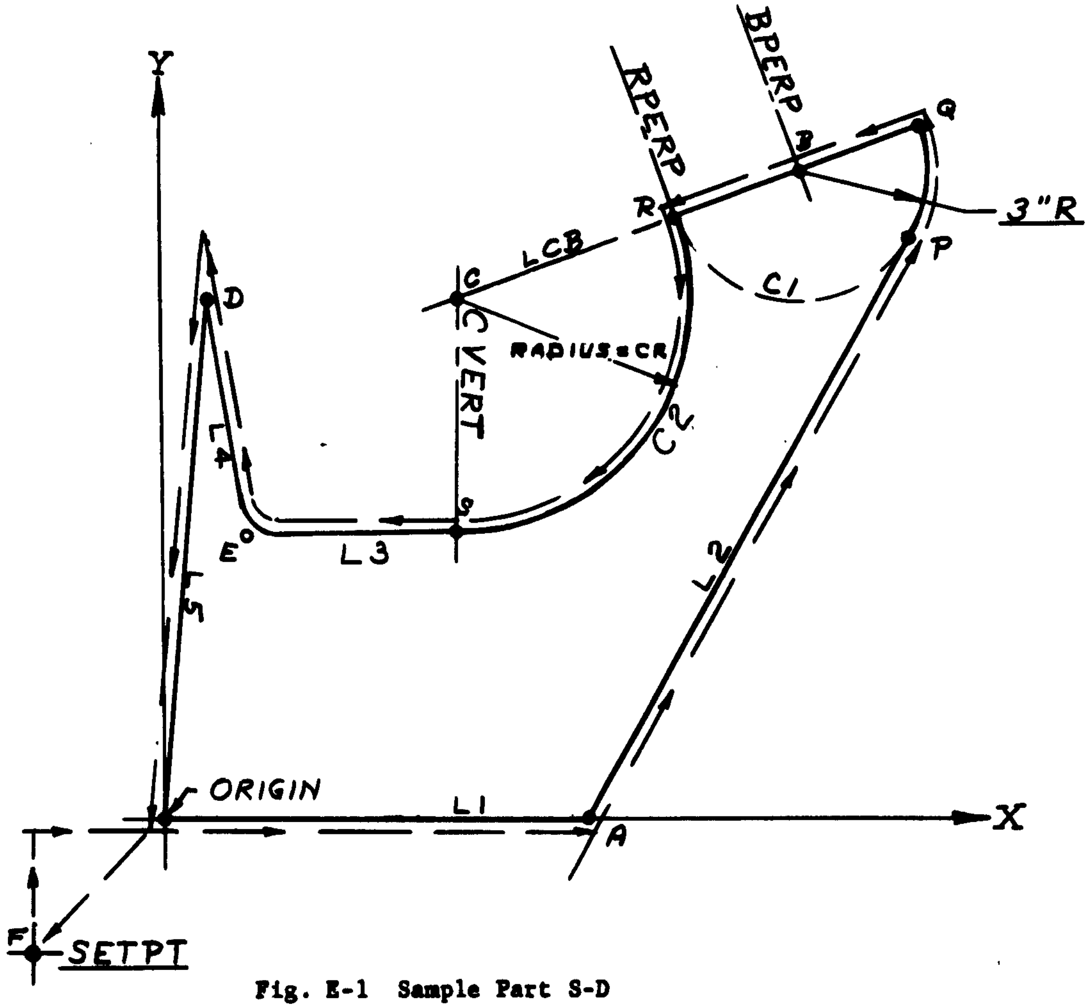


Fig. E-1 Sample Part S-D

APT NUMERICAL CONTROL MANUSCRIPT
Form 60-325 (1-60)

JOB NO.

OPERATION DESCRIPTION	ISSUE NO.	DATE	PROGRAMMER	EXT.	MODEL NO.	PART NO.	SHEET	OF
			BOB FEENY			SAMPLE PART S-D		
	ENGR. CHANGE		CHECKED BY	ACCOUNT NO. / SALES ORDER / DASH		PART DESCRIPTION		
				EWO NO.	T.O. SERIAL			
					ORGN. NO.	OPER. NO.	TAPE NO.	

SYMBOL (1 2 3 4 5 6)	= (7)	APT MACHINING INSTRUCTIONS (8 … 72)	SEQUENCE NO. (73 74 75 76 77 78 79 80)
PARTNØ	=	S-D	
		CUTTER /0.040 $$ KERF 0.080" IN DIAM	
		TØLER /0.01	
		FEDRAT / 20	
		2D CALC $$ CALCULATIONS IN TWO DIMENSIONS ONLY	
		TV PLØT $$ TO OBTAIN PLOTTED PICTURE	
		FRØM /(SP = PØINT /-3,-3,0)	
		ØNFLAM, ØNØXY, DWELL, 25 $$ TO ACTUATE TORCH	
		INDIR, VECTOR / 0, 1, 0	
		GØTØ /(L1=LINE/(PTO=PØINT/0,0),(PTA=PØINT/10,0)	
		TLRGT, GØRGT / L1	
		GØLFT /(L2=LINE/PTA, RIGHT, TANTO $	
		(C1 = CIRCLE /CENTER (PTB=PØINT/15,15), RADIUS, 3))	
		GØFWD /C1	
		GØLFT, LINE/PTB (PTC = PØINT/7,12)	
		GØLFT /(C2 = CIRCLE /CENTER, PTC, SMALL, TANTØ, C1)	
		GØFWD /(L3 = LINE /(PTS= PØINT /C2, ATANGL, -90) ATANGL, 0)	
PTE	=	PØINT/INTØF, L3,(LINE/2,0,2,1)	
		GØFWD, CIRCLE /L3, YLARGE, (L4=LINE/(PTD=PØINT/1,12) PTE)$	
		XLARGE, RADIUS, 1	
		GØFWD/L4	
		GØLFT /(LINE/PTD, PTO) P[illegible] L1	
		OFFLAM $$ [illegible] OFF TORCH	
		GØTØ /SP	
		END	

Fig. E-2 APT Programming Form

IBM

AUTOMAP CODING FORM

Printed in U.S.A.

Program SAMPLE PART S-D
Coded By BOB FEENY
Checked By

Identification 74 80

Date 17 DEC 63
Page 1 of 1

R FOR REMARK — N, S, P — FOR CONT. 72 73

LABEL	=	AUTOMAP STATEMENT
REMARK		SAMPLE PART S-D
START	=	DØMAC/-3.0,-3.0,0.0,0.04,0.01,20.0
		INDIR,VECTØR/0.0,1.0,0.0
L1	=	GØTØ,LINE/0.0,0.0,1.0,0.0
		GØRGT/L1
C1	=	CIRCLE/15.0,15.0,3.0
		GØLFT,LINE/10.0,0.0,RIGHT,TANTØ,C1
		GØFWD/C1
L CB	=	GØLFT,LINE/7.0,12.0,15.0,15.0
BPERP	=	LINE/15.0,15.0,PERPTØ,L CB
RPERP	=	LINE/PARLEL,BPERP,XSMALL,3.0
PTC	=	PØINT/7.0,12.0,0.0
C2	=	GØLFT,CIRCLE/CENTER,PTC,TANTØ,RPERP
CVERT	=	LINE/PTC,PERPTØ,L1
PTS	=	PØINT/YSMALL,INTØF,C2,CVERT
L3	=	GØFWD,LINE/PTS,ATANGL,0.0
EVERT	=	LINE/2.0,0.0,2.0,1.0
PTE	=	PØINT/INTØF,L3,EVERT
L4	=	LINE/PTE,1.0,12.0
		GØFWD,CIRCLE/L4,XLARGE,L3,YLARGE,RADIUS,1.0
		GØFWD/L4
		GOLFT,LINE/0.0,0.0,1.0,12.0
END	=	DØMAC/-3.0,-3.0,0.0,L1

Fig. E-3 AUTOMAP Programming Form

NUMERICAL MACHINE TOOL CONTROL

UNIVAC SOLID STATE COMPUTER PROGRAM

INPUT MANUSCRIPT

USS-80

Remington Rand Univac
DIVISION OF SPERRY RAND CORPORATION

PAGE 1 OF 1

SEQ. NO.	ADD	CURVE NAME	GEOM. SOL. NO.	REQ. (1)	REQ. (2)	REQ. (3) KT	REQ. (3) SD	POINT NAME	S X	X COORDINATE/	S Y	Y COORDINATE	S Z	Z - COORD. OR RADIUS/	FEED RATE	L/R	OFFSET DIST.	PART NO.	COMMENTS	PROGRAMMER'S NOTATION
1 — 3	4	5 — 8	9 — 11 12 13	14 — 17	18 — 21	22 23	24 25	26 — 29	30	31 — 34 35 — 38	39	40 — 43 44 — 47	48	49 — 52 53 — 56	57 — 59 60	61	62 — 64 65 — 67	68 — 70	71 — 80	
1			FROM					SETP	–	3	–	3		0	20		0		SAMPLE PART 3-D	
1A			XMAC1																	
1B			DELAY							25									PROGRAMMER	
1C			XMAC2																BOB FEENY	
1D			DELAY																	
1E			XMAC3																DATE 11-13-63	
1F			DELAY																	
2		L1	LANGL																	
3		L1	11			GO		ORIG								R	05			
4		L1	11			GO		PT A		10										
5		L2	31	PT A				PT P		15		15	–	3						
6		L2				GO														
7		C1	7A		PT P	CC				15		15								
8		LCB	30	C1						7		12								
9		C2	63		C1	CW				7		12								
10			PANGL	C2				PT S					–	90						
11		L3	LANGL	PT S										180						
12		L3				GO														
13		LN E	LANGL							2				90						
14			01	LN E	L3			PT E												
15		L4		PT E								12								
16		PT D								1		12	–	0		L	05			
17		L5		PT D	ORIG	GO		ORIG								R	05			
17A			XMAC4																	
18						GO		SETP												
19			FINI																	

Fig. E-4 SYMPAC Coding Form

Appendix F

COMPUTER PLOTS OF FULL PLATES

Figures F-1 through F-8 are plots of fully nested parts. These are actual drawings made by the computer-plotter employing the final numerical control tape as input. These plots show in small scale the actual paths which will be traversed by the cutting torch.

The purpose of making these plots is to check the accuracy of the final tape. Errors found at this point usually result from inaccuracies in the nesting procedure. Figure F-5 shows the plot of a plate containing many errors in nesting, and the same plot as corrected.

In addition to using these plots as a check on the N/C tape, the plots can be used to show the markings which must be put on the cut parts to identify them. Figure F-8 shows a plate plot marked in this manner.

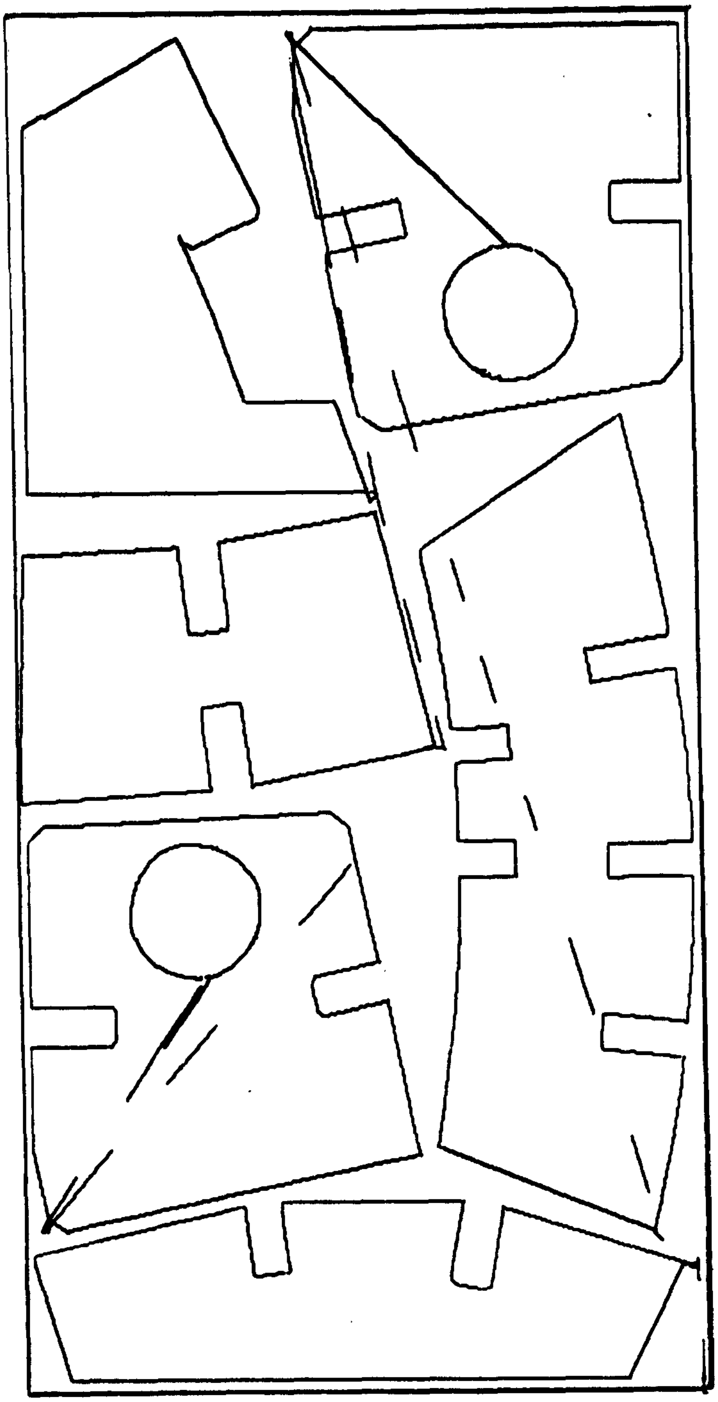


Fig. F-1 Miscellaneous Floor Frames
(DLG-33)

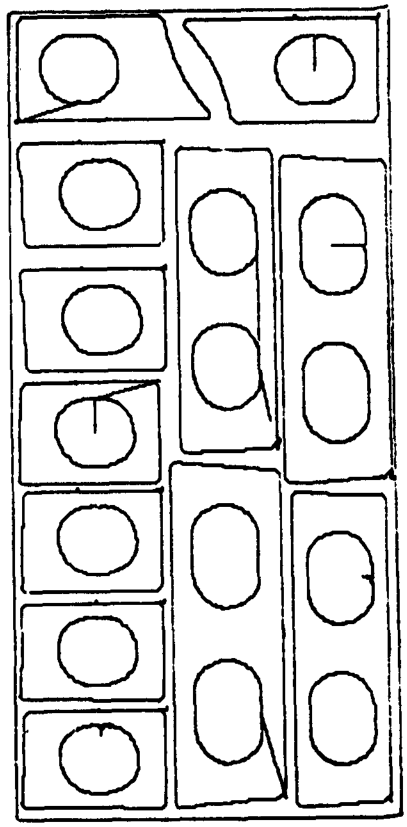


Fig. F-2 Transverse Frame 12
(DLG-33)

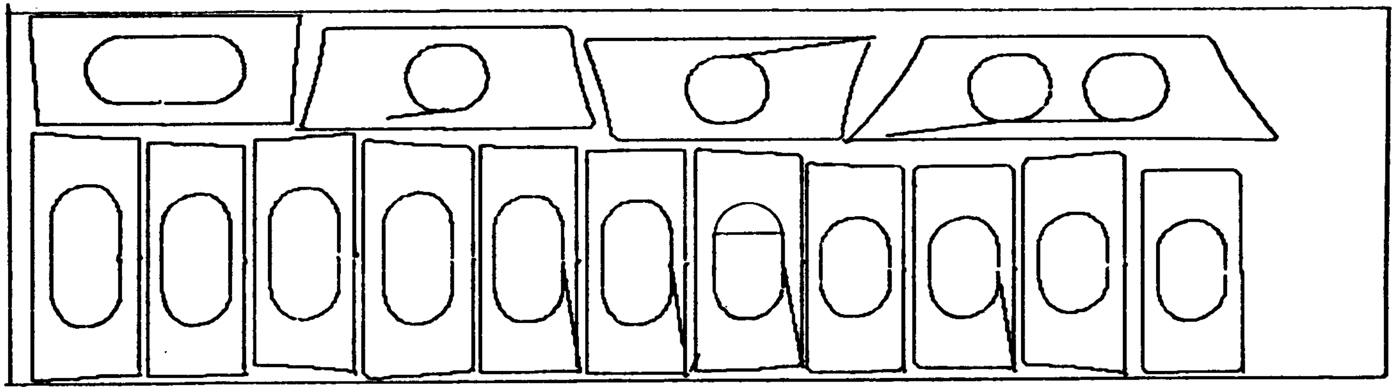


Fig. F-3 Transverse Frames 8-4/5 and 9-3/5 for DLG-33

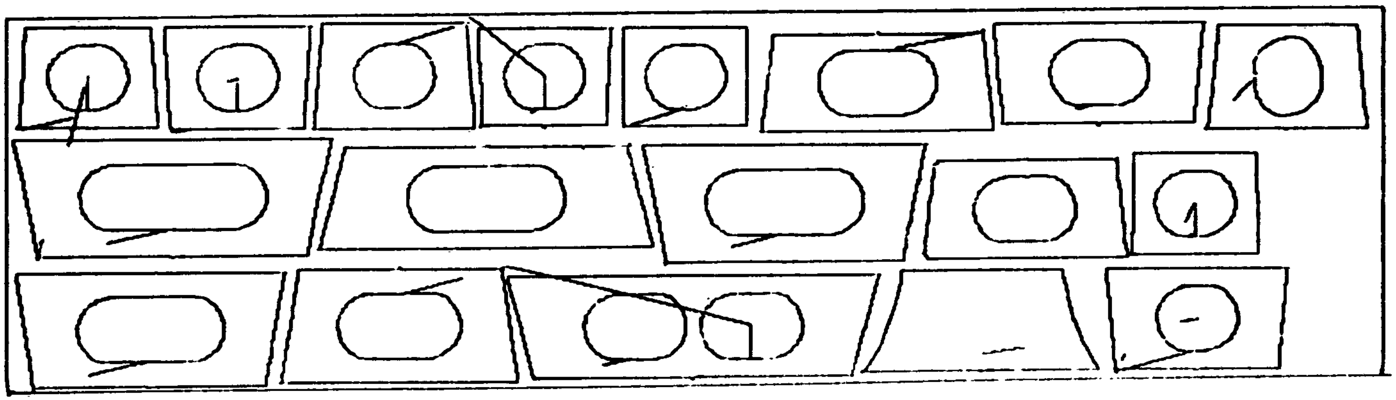


Fig. F-4 Transverse Frames 6 and 7 for DLG-33

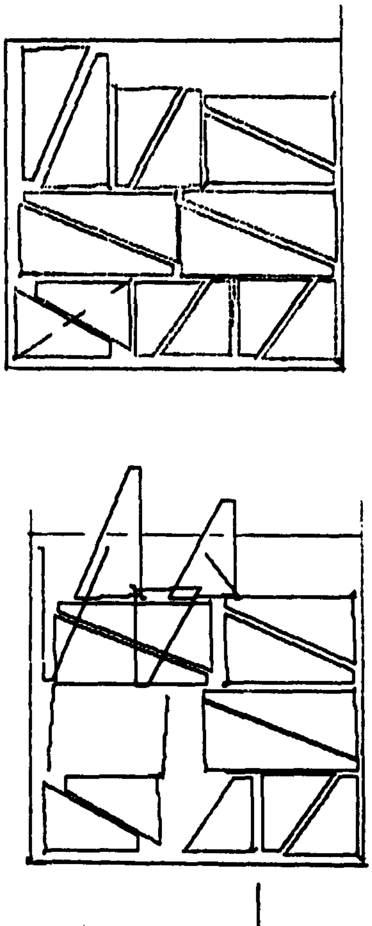


Fig. F-5 Bilge Keel Supports (DLG-33)
The lower sketch shows parts incorrectly nested as shown by plotter before cutting plate. The upper sketch shows corrected nesting of parts.

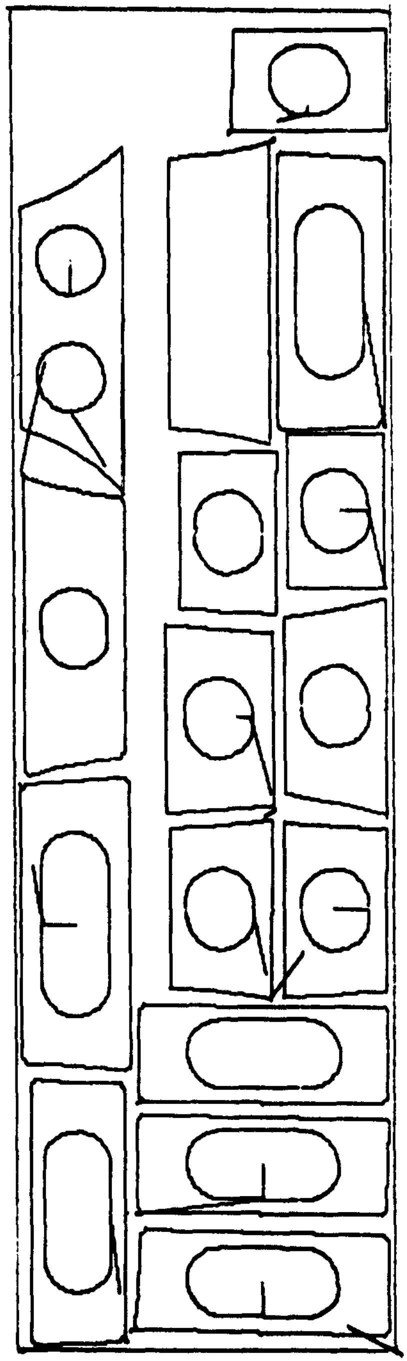


Fig. F-6 Transverse Frame 7 (DLG-33)

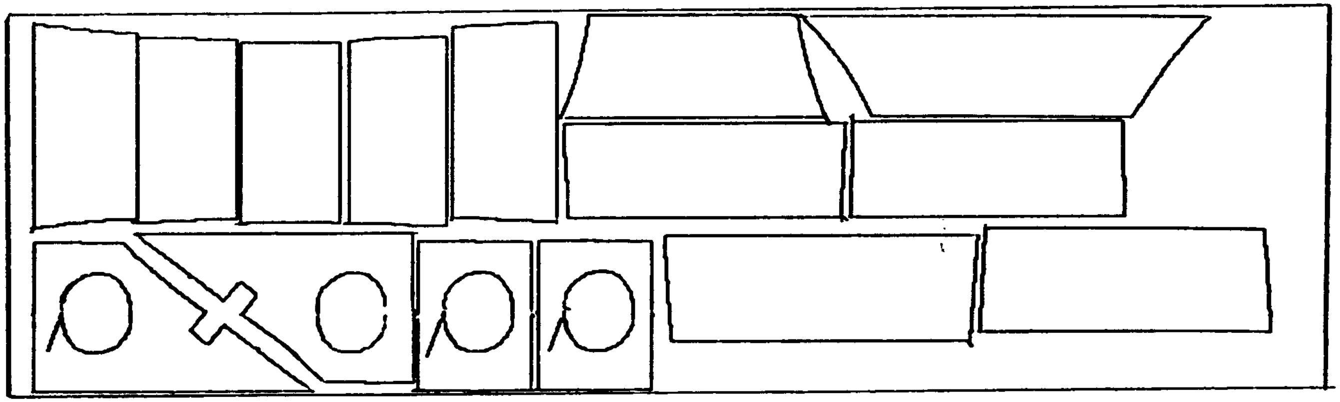


Fig. F-7 Transverse Frame 8, DLG-33

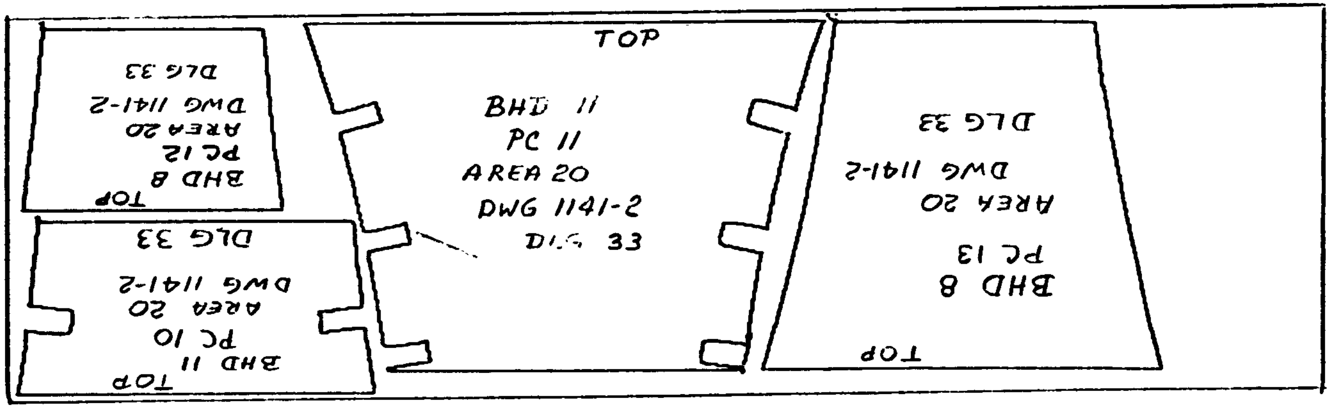


Fig. F-8 Transverse Frames 8 and 11, DLG-33, with Identification Markings